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A RISK AND COST ANALYSIS OF TRANSPORTING AND STORING GULF OF ALASKA OUTER CONTINENTAL SHELF OIL

Booz-Allen and Hamilton, Incorporated

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The U.S. Environmental Protection Agency

Office of Planning and Management
Washington, D. C.

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BOOZ · ALLEN APPLIED RESEARCH

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The objectives of this study were to measure the risk of oil spills and estimate the costs associated with alternative transport and intermediate storage systems from OCS oil fields to United States west coast terminals and refineries. This was accomplished through a review of past oil spill statistics and analyses, and application of the data to the specific conditions of Gulf of Alaska OCS. To assist in specifying these conditions, a series of strictly hypothetical scenarios were established. Representative production sites were selected without the benefit of dependable estimates of specific reserve locations.

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I. INTRODUCTION

1. OBJECTIVES OF THE STUDY

It has been proposed that the Federal Government offer for lease approximately 1.8 million acres of the Gulf of Alaska Outer Continental Shelf (OCS) for the purpose of developing oil and gas reserves. The lease sale would be held in accordance with the Outer Continental Shelf Lands Act of 1953.

The objectives of this study were to measure the risk of oil spills and estimate the costs associated with alternative transport and intermediate storage systems from OCS oil fields to United States west coast terminals and refineries. This was accomplished through a review of past oil spill statistics and analyses, and application of the data to the specific conditions of Gulf of Alaska OCS. To assist in specifying these conditions, a series of strictly hypothetical scenarios were established. Representative production sites were selected without the benefit of dependable estimates of specific reserve locations.

2. DESCRIPTION OF THE LEASE AREA

The proposed lease area is shown in Figure I-1. It is located in the northern Gulf of Alaska between Middleton Island and Icy Bay. Depths in the lease area range from 15 to 350 fathoms, but are predominantly less than 100 fathoms.

The U.S. Geological Survey (USGS) has estimated the potential recoverable oil reserves in this area to be from 100 million to 2.8 billion barrels. They estimate a 95 percent chance of discovering at least 100 million barrels, with only a five percent chance of achieving 2.8 billion barrels.

3. OFFSHORE PRODUCTION SITE SELECTION

Four offshore lease tracts were selected as being representative production sites in the Gulf of Alaska. The locations of these sites

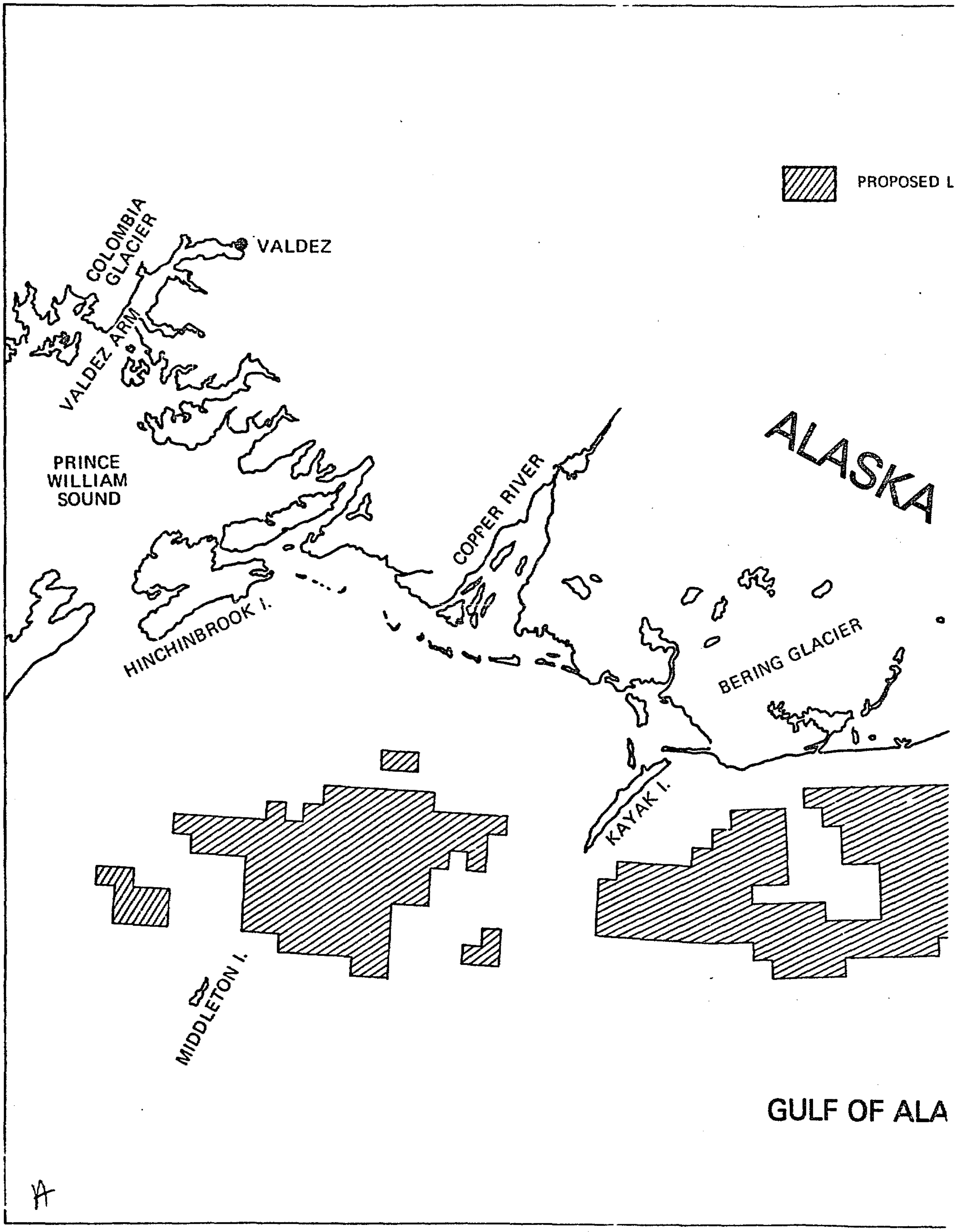
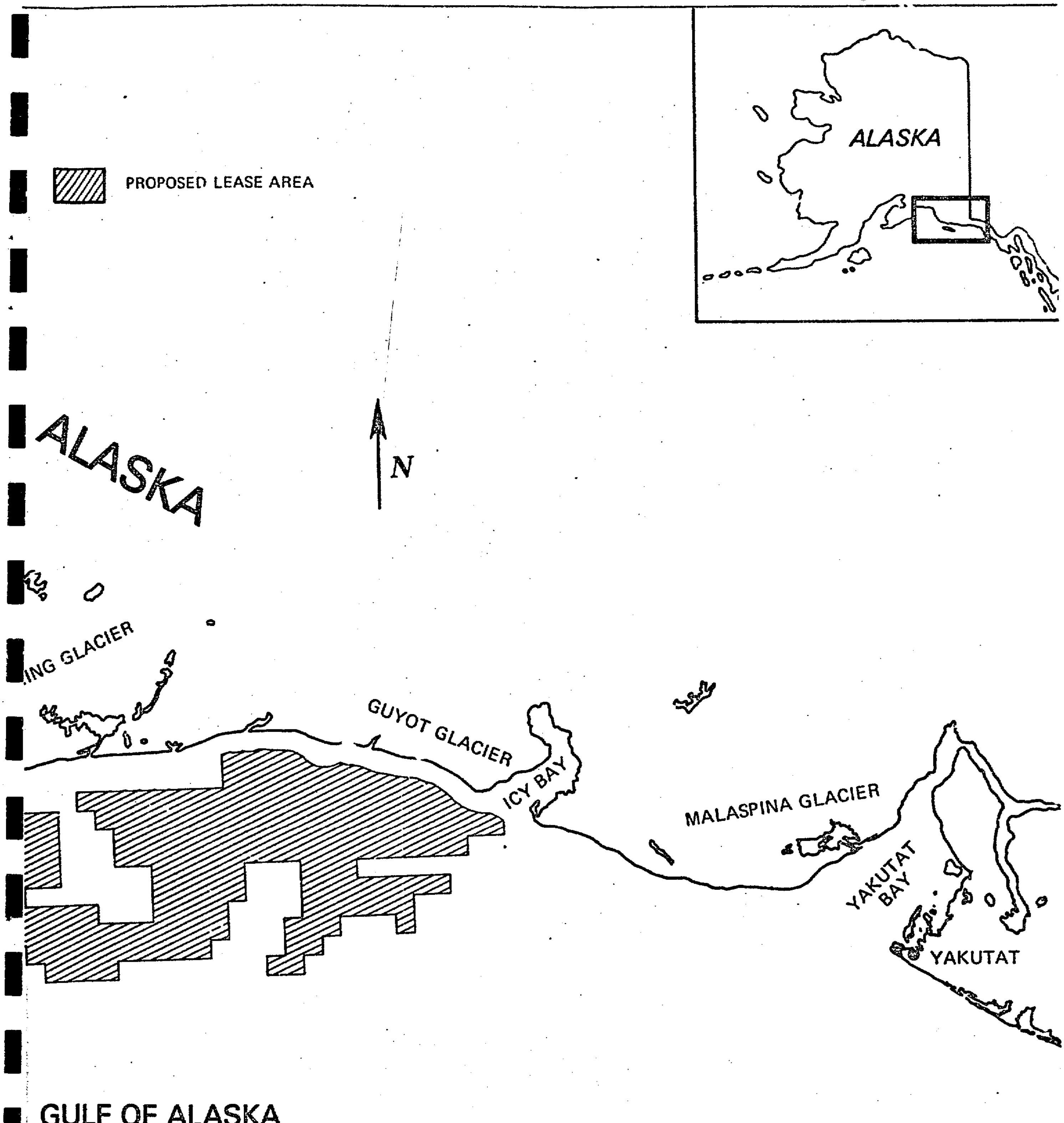

PROPOSED L
COLOMBIA GLACIER
VALDEZ
VALDEZ ARM
PRINCE WILLIAM SOUND
COPPER RIVER
ALASKA
HINCHINBROOK I.
BERING GLACIER
KAYAK I.
MIDDLETON I.
GULF OF ALA
A

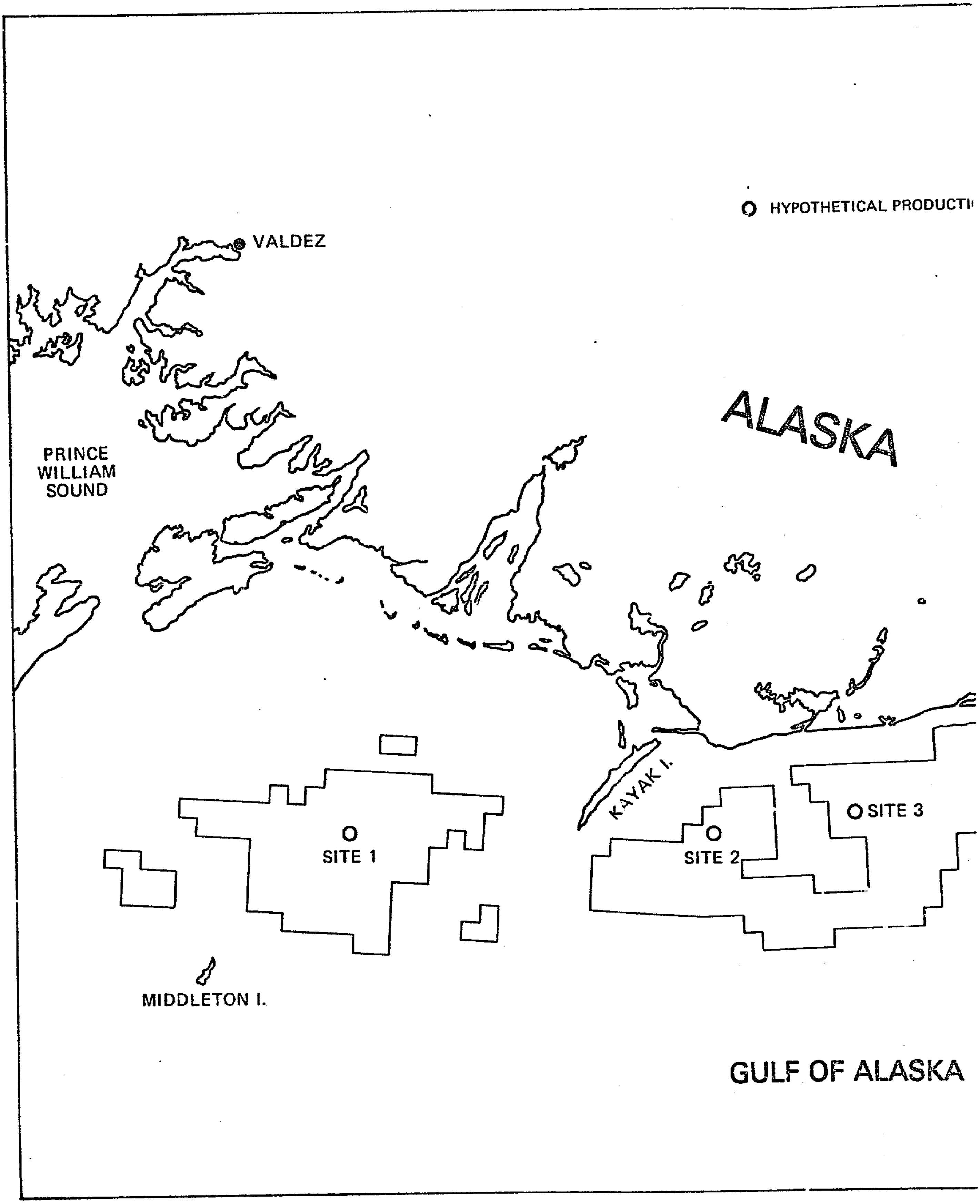
FIGURE I-1
Proposed Lease Area



are depicted in Figure I-2. The selection process was designed to include consideration of a variety of depths, bottom conditions, and distances to shore facilities. An area's production potential was also considered but was of little value due to the absence of reliable site specific reserve information. Each site was assumed to contain a fourth of the Gulf's estimated reserves, resulting in production site reserve estimates of 25 to 700 million barrels. To account for the possibility of a production site containing more than one fourth of the total reserves, or the USGS recovery rate assumption of 32 percent being too conservative due to improving technology, the maximum reserve estimate for each production site was raised to two billion barrels of oil.

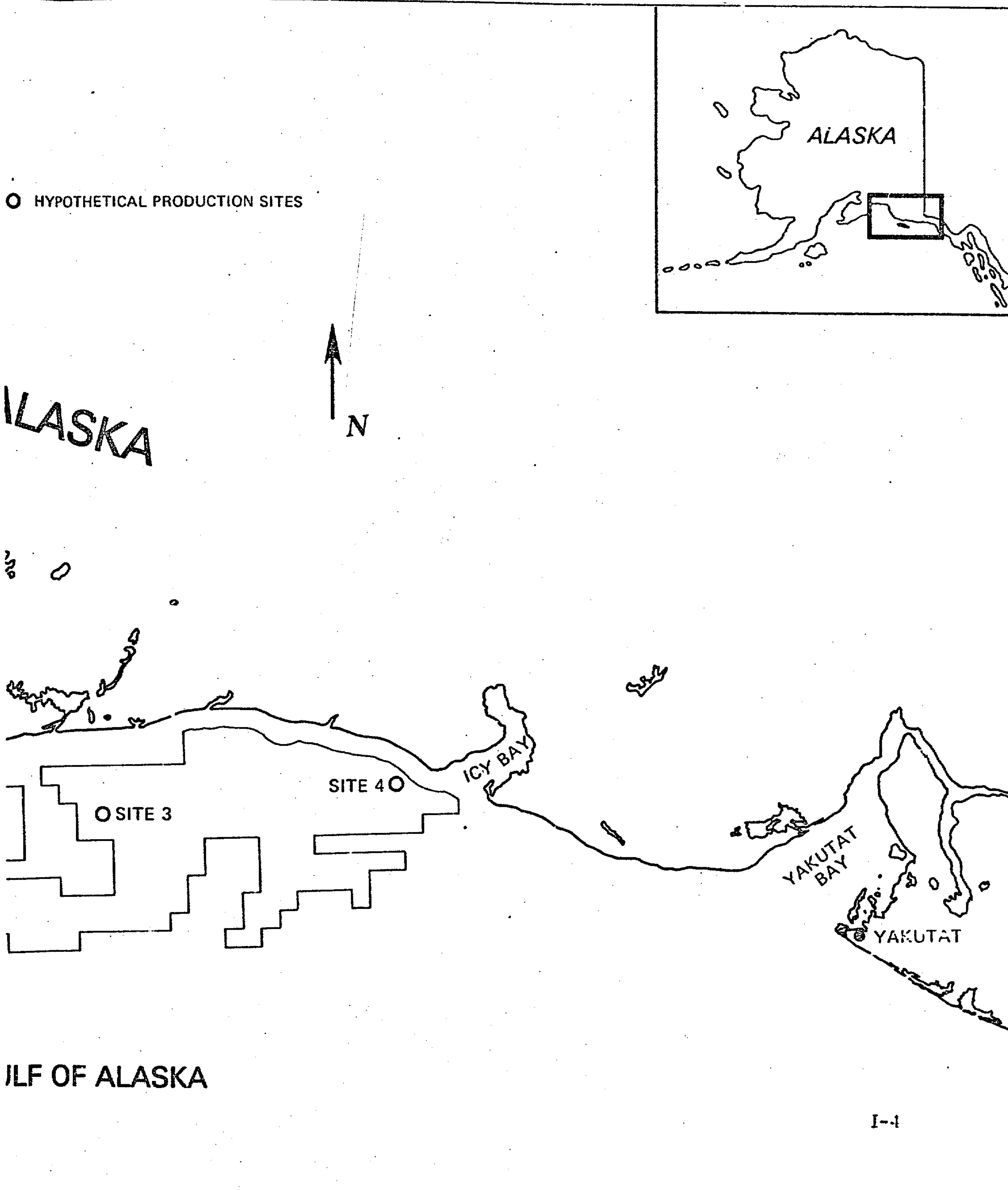
The sites indicated in Figure I-2 are described below:

- Site 1 - Tract 236 - Middleton Island
  - Average depth: 50 fathoms
  - Production site depth: 61 fathoms
  - Distance from nearest point ashore: 40 miles
  - Distance from Valdez: 120 miles
  - Distance from Yakutat: 230 miles
  - Bottom characteristics: Hard bottom with negligible slope, near fault
- Site 2 - Tract 186 - Icy Bay
  - Average depth: 50 fathoms
  - Production site depth: 54 fathoms
  - Distance from nearest point ashore: 14 miles
  - Distance from Valdez: 180 miles
  - Distance from Yakutat: 150 miles
  - Bottom characteristics: Mud bottom with moderate slope, near fault



HYPOTHETICAL PRODUCTI
VALDEZ
ALASKA
PRINCE WILLIAM SOUND
KAYAK I.
SITE 1
SITE 2
SITE 3
MIDDLETON I.
GULF OF ALASKA

FIGURE I-2
Hypothetical Production Site



- High density seabird foraging area, near high intensity commercial fishing area

- Site 3 - Tract 150 - Icy Bay
  - Average depth: 100 fathoms
  - Production site depth: 95 fathoms
  - Distance from nearest point ashore: 13 miles
  - Distance from Valdez: 200 miles
  - Distance from Yakutat: 130 miles
  - Bottom characteristics: Mud bottom with steep slope
  - High density seabird foraging area. High intensity commercial fishing area

- Site 4 - Tract 122 - Icy Bay
  - Average depth: 25 fathoms
  - Production site depth: 16 fathoms
  - Distance from nearest point ashore: 6 miles
  - Distance from Valdez: 250 miles
  - Distance from Yakutat: 90 miles
  - Bottom characteristics: Soft bottom with moderate slope between two faults.

These sites are considered to be moderate to high environmental risk locations. Due to the hostile environment there are no inherently low risk sites in the Gulf of Alaska.

4. DESCRIPTION OF THE PHYSICAL ENVIRONMENT

The physical environment of the lease area includes a wide variety of adverse conditions. Each of these hazards is discussed below, and wind, visibility, and sea states are presented in Table I-1.

Table I-1
Wind, Visibility, and Sea Conditions - Gulf of Alaska

MONTH	PERCENT OF TIME					MEDIAN DAYS			
						GALE		<2NM VISIBILITY	
	WIND ≥34KTS	VISIBILITY ≤5NM	SEAS ≥5FT	SEAS ≥8FT	SEAS ≥12FT	DURATION	INTERVAL	DURATION	INTERVAL
JANUARY	10	20	30	10	2	0.2	0.7	0.2	1.7
FEBRUARY	5	20	30	10	2	0.2	1	0.2	0.7
MARCH	5	15	30	10	2	0.2	1	0.2	1.4
APRIL	5	15	20	5	2	0.25	0.7	0.2	2
MAY	5	15	20	5	2	0.2	2.5	0.2	0.8
JUNE	0	15	20	5	2	0.2	9	0.2	0.6
JULY	0	20	15	2	2	-	-	0.2	0.6
AUGUST	0	20	15	2	2	-	-	0.2	0.3
SEPTEMBER	5	20	15	2	2	0.2	2.5	0.2	1
OCTOBER	5	15	40	20	10	0.2	1.1	0.2	4
NOVEMBER	5	15	40	20	10	0.2	0.8	0.2	1.7
DECEMBER	10	5	40	20	10	0.2	0.7	0.2	2.5

NOTE: SEAS DATA ARE SEASONAL AVERAGES.

SOURCES: "PERCENT OF TIME" DATA FROM CLIMATOLOGICAL AND OCEANOGRAPHIC ATLAS FOR MARINERS: VOLUME II, NORTH PACIFIC OCEAN (1961).

"MEDIAN DAYS" DATA FROM MARINE CLIMATIC ATLAS OF THE WORLD: VOLUME II, NORTH PACIFIC OCEAN (NAVAIE 50-1C-529, 1956).

(1) Wind

The Gulf of Alaska is on primary North Pacific storm tracks and is a development site of cyclonic air masses. Except during the summer months, winds exceed 34 knots five to ten percent of the time and are predominantly easterly to northeasterly. Maximum wind 30 feet above the surface is approximately 80 knots, with a 50-year recurrence interval. These conditions are summarized in Table I-1.

(2) Sea State

Sea states are least severe in summer and most severe in autumn. In the latter season, significant seas exceed five feet 40 percent of the time, eight feet 20 percent of the time, and twelve feet ten percent of the time. The maximum significant wave height for the lease area is 45 feet, with a 50-year recurrence interval. Sea states for the Gulf of Alaska are summarized in Table I-1.

(3) Visibility

The Alaska Current and the seasonal Davidson Current contribute to frequent and prolonged periods of low visibility in the Gulf of Alaska. Except during December, visibility is less than five miles from 15 to 20 percent of the time. Median duration of periods with less than two mile visibility ranges from six hours in October to 36 hours in February, with median recurrence interval less than one day for the latter. Table I-1 provides information on visibility conditions characteristic of the Gulf of Alaska.

(4) Precipitation

Annual precipitation in the Gulf of Alaska ranges from about 100 inches to over 200 inches. Shore points near the lease areas experience total snowfall often exceeding 200 inches; however, snow accumulation is limited by relatively moderate temperatures.

(5) Sea Ice

There are many glaciers located near the Gulf of Alaska lease area. Most of these have glacial faces at the rear of a small bay, with a moraine bar at the entrance to the bay. The bars prevent icebergs formed at the glacial face from entering the Gulf of Alaska until they are reduced to a harmless size.

One notable exception has been the subject of recent USGS study. The Colombia Glacier, located west of Valdez on the Prince William Sound, appears to be on the verge of a rapid retreat, with little obstruction of the icebergs it would release into Colombia Bay. Wind and currents could carry these bergs into the Valdez Arm, through which all Valdez shipping traffic must pass. The possibility of this occurrence is not sufficiently explored to permit a risk analysis at this time. However, USGS research proposed for the next few years may further define the potential for iceberg problems.

(6) Earthquake

The Gulf of Alaska is a seismically active area with a high probability of severe earthquake occurrence during the active life of a typical oil field. The predicted recurrence interval for various earthquake magnitudes is depicted in Figure I-3. As shown in the chart, one earthquake of Richter magnitude 8.0 or greater can be expected during a twenty year field life. If the seismic gap theory*is accepted, future earthquakes are expected to occur in and around the lease area, specifically, portions of the shelf and slope east of Middleton Island.

Secondary effects of an earthquake, such as landslides, turbidity currents and lateral soil translations, must be considered during OCS development. Figure I-4 shows the location

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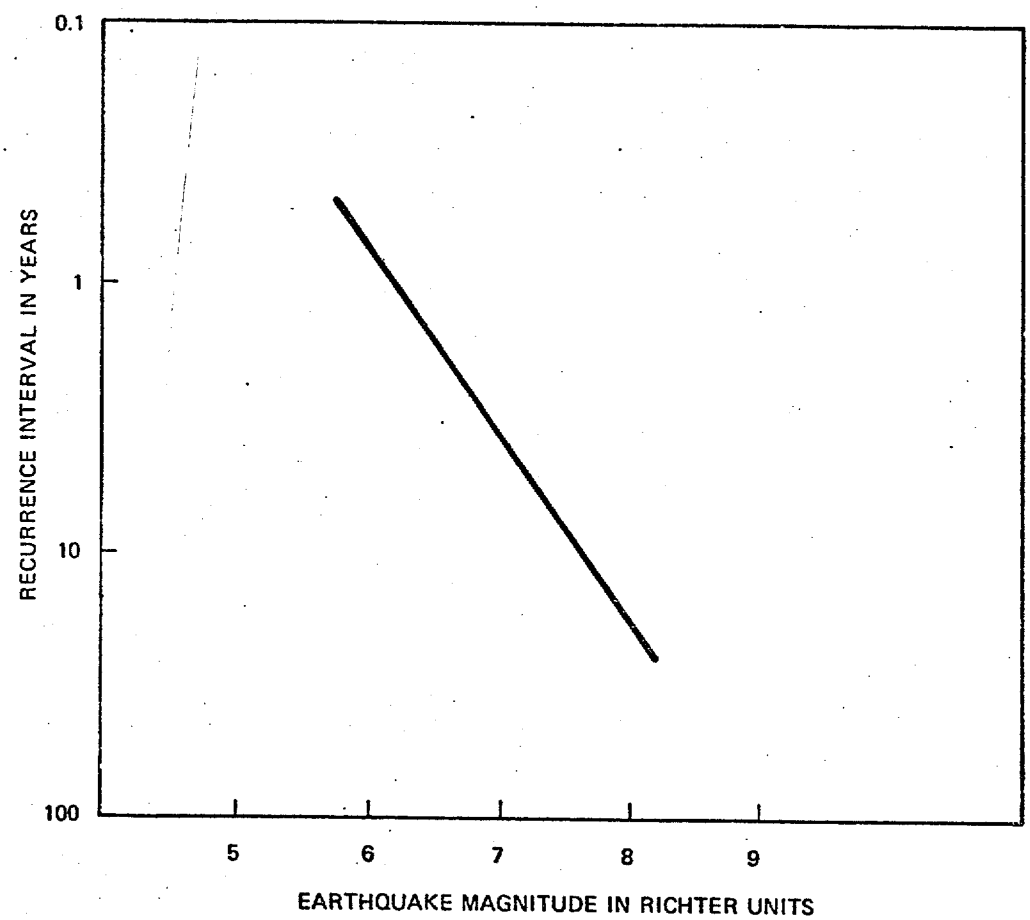
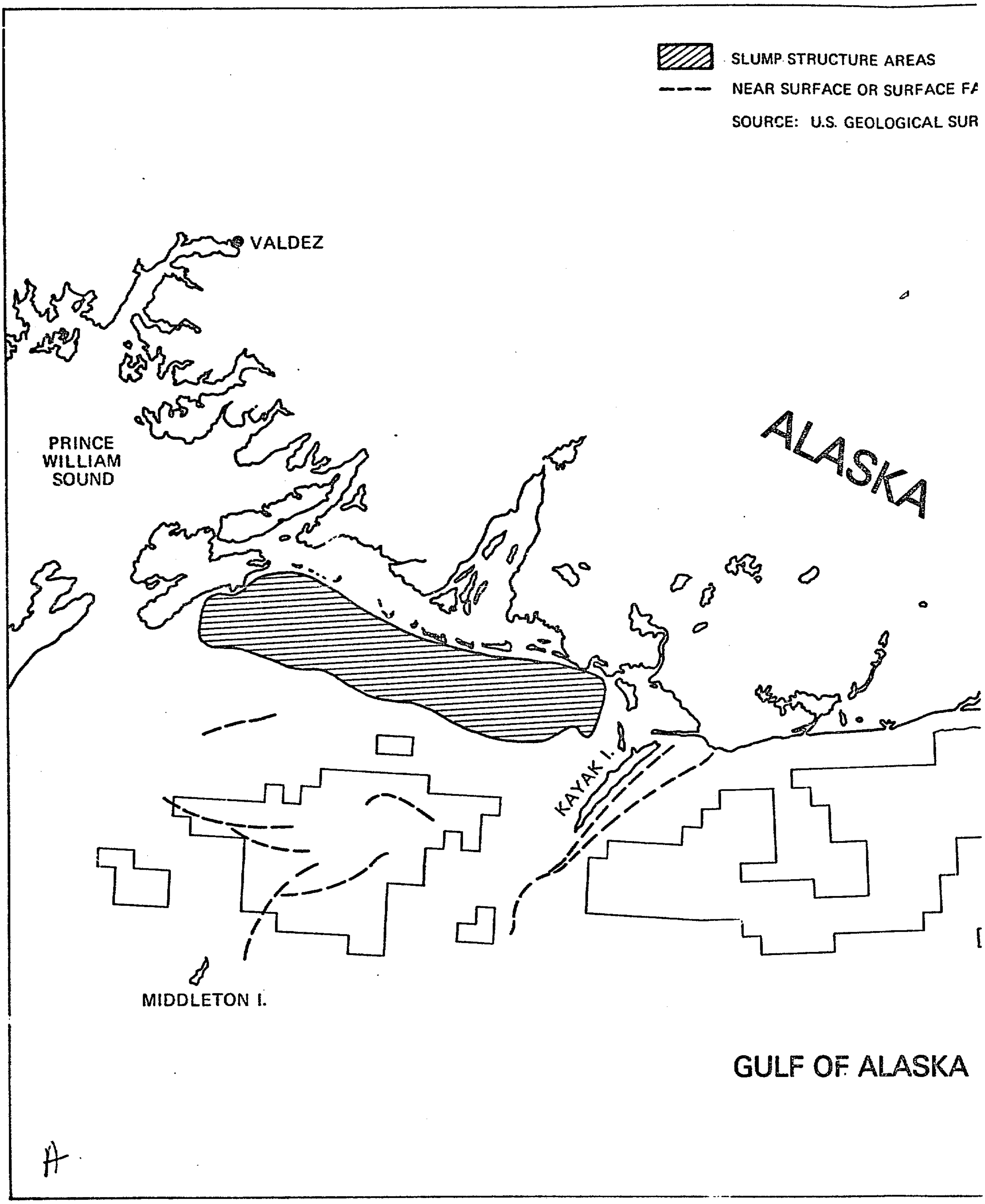
* Sykes, L. R., 1971. "Aftershock Zone of Great Earthquakes, Seismicity Gaps and Earthquake Prediction for Alaska and the Aleutians"

FIGURE I-3
Gulf of Alaska
Earthquake Recurrence

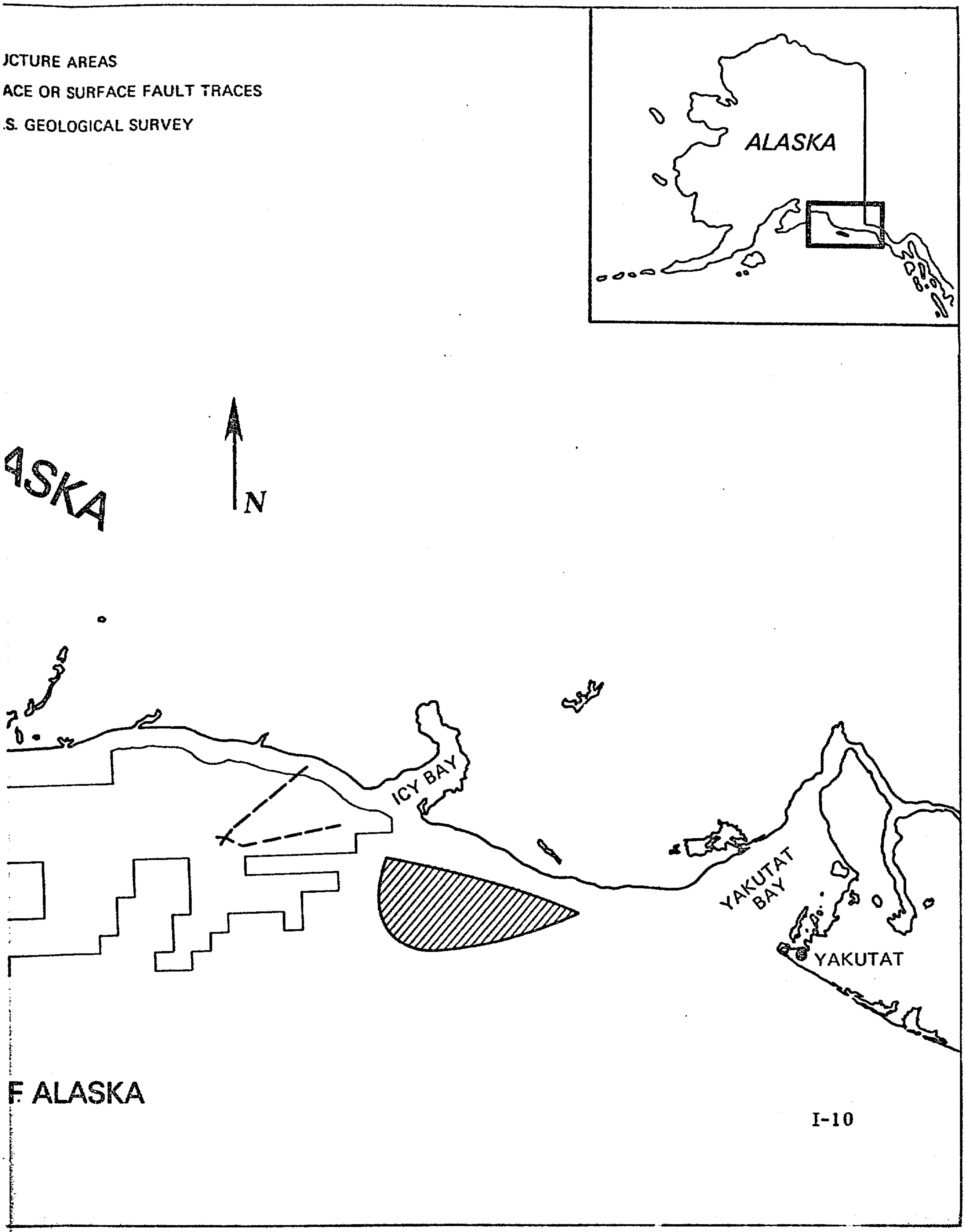


SOURCE: CEQ REPORT, 1974



SLUMP STRUCTURE AREAS
NEAR SURFACE OR SURFACE FA
SOURCE: U.S. GEOLOGICAL SUR
VALDEZ
PRINCE WILLIAM SOUND
ALASKA
KAYAK I.
MIDDLETON I.
GULF OF ALASKA
A

FIGURE I-4
Gulf of Alaska Soil Structure



B

of near-surface faults and areas of known slump structure. Other tracts of potentially unstable soils are scattered throughout the lease area.

(7) Tsunami (Seismic Sea Waves)

Tsunami are usually a result of massive shifts in the sea floor, occurring during an earthquake. These waves increase in height as they approach shore and can be particularly damaging to harbor facilities. An approximate relationship between earthquake magnitude and tsunami height is presented in Figure I-5. This figure, together with Figure I-3, may be used to predict expected tsunami occurrence in the Gulf of Alaska.

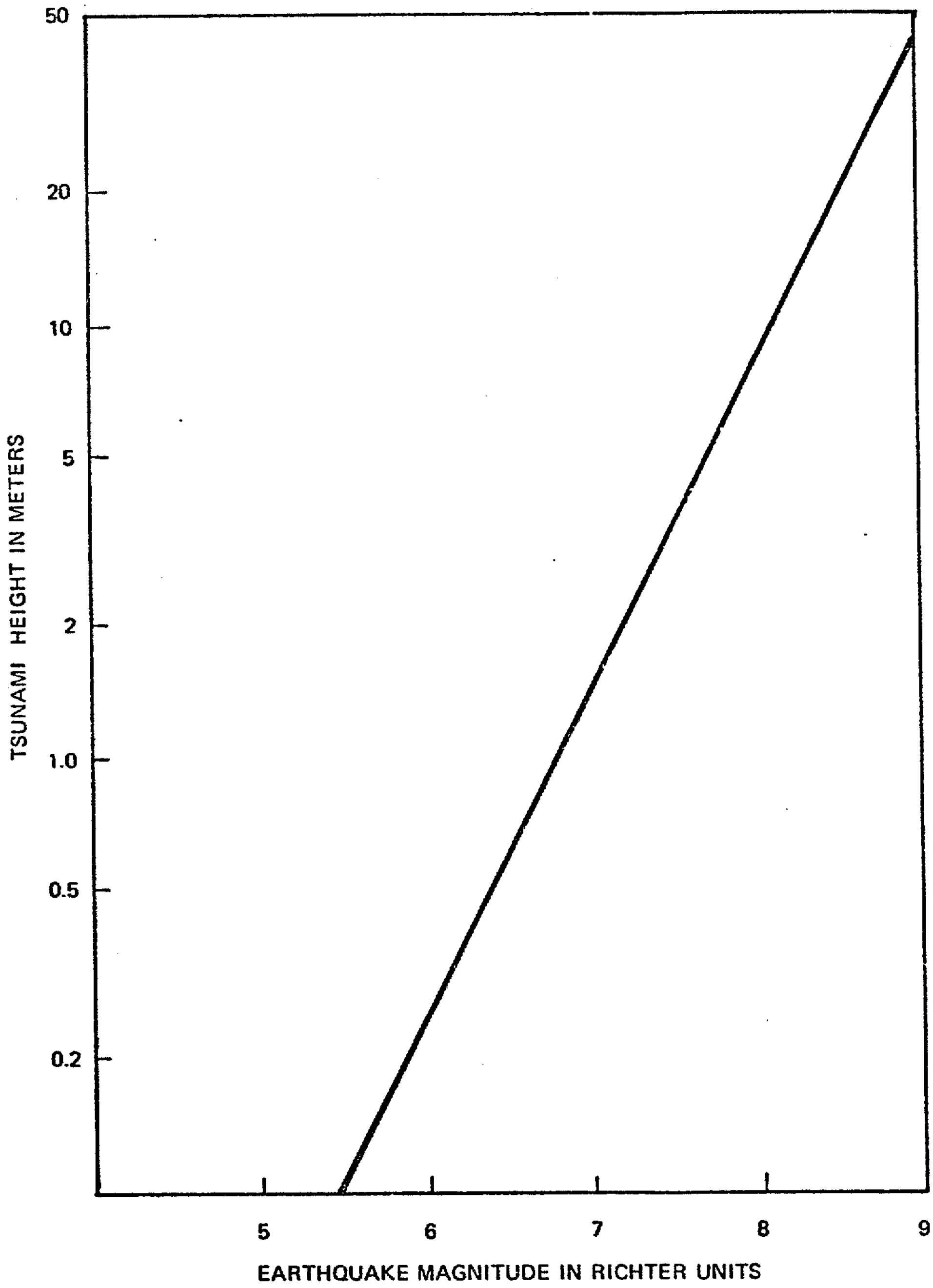
(8) Shore Environment

Coastal vegetation includes watersedge tundra, meadows and barren, and some hemlock and spruce forest. Much of the coast in the vicinity of the lease area is ice covered. The interior is glacier covered except at mountain peaks. The nearest significant community, Yakutat, and the adjoining bay are effectively surrounded by the Malaspina, Lucia, Hubbard, Art Lewis, Novatak, Alsek and Grand Plateau glaciers. West of Yakutat, Malaspina is the only coastal glacier that reaches to the Gulf shore at present.

Apart from Yakutat, the coast in the vicinity of the lease area is virtually uninhabited. However, this land area is tentatively claimed for reversion to the State of Alaska and remains subject to native settlement claims. The impact of these claims on shore development for oil production cannot be determined at this time.

The next chapter contains a review of current transportation and storage technology, and a description of the candidate transportation and storage systems designed for each hypothetical production site.

FIGURE I-5
Tsunami Height



SOURCE: CEQ REPORT, 1974

II. CANDIDATE TRANSPORTATION AND STORAGE SYSTEMS

1. TRANSPORTATION ALTERNATIVES

The two basic modes of crude oil transportation to be considered in the Gulf of Alaska are tankers and pipelines. Current and developing equipment for each mode is discussed in the following sections. Barge transportation is not considered feasible in the Gulf of Alaska due to severe storms which occur frequently. While barges are used in coastal waters for trade between onshore ports, their use at a single point moor (SPM) is considerably more hazardous. If an unmanned barge breaks its towline or moorings in rough seas, there is a high risk of the barge grounding before it can be recovered. The use of a tanker minimizes this risk.

(1) Tanker Transportation

Crude oil tankers are a well developed means of transportation, and few changes are expected during the Alaskan OCS field life. It is assumed, for the purposes of this study, that tankers used in the Alaskan trade will incorporate segregated ballast tank design. Since short-haul tankers and direct shipment long haul tankers must de-ballast at the SPM, cheaper onshore ballast processing facilities cannot be used. Other methods of handling ballast water, such as offshore processing stations, may be feasible and would not affect the outcome of the analysis. The key assumptions are that oily ballast water will not be dumped in the Gulf of Alaska, and some economic penalty must be paid for this benefit. An estimate of the averted spill volume is contained in Chapter IV.

While tankers remain essentially the same, their mooring systems are undergoing rapid improvements to satisfy new demands. Three mooring concepts are considered in this study. The oldest form is a conventional dock facility. A more recent development, placed in service 16 years ago, is the SPM.

The SPM system consists of a flat, cylindrical buoy held in place by a series of anchors and chains. The buoy is connected to the platform via a submarine manifold and ocean floor base. A turntable on top of the buoy carries the pipe from a central buoy swivel to the side of the buoy where it connects to a floating hose or hoses leading to the tanker. The tanker is made up to the buoy by means of two nylon hawsers running from the buoy turntable to the bow of the ship. There are approximately 150 SPM's of this type in service throughout the world today.

The third type of moor is a larger, heavy weather SPM. It is a manned articulated tower and has a crane for hose and hawser handling, eliminating the need for a support vessel. This SPM design can be utilized in deeper water, and has expanded operational limits in foul weather. Three similar articulated tower SPM's have been put into service recently.

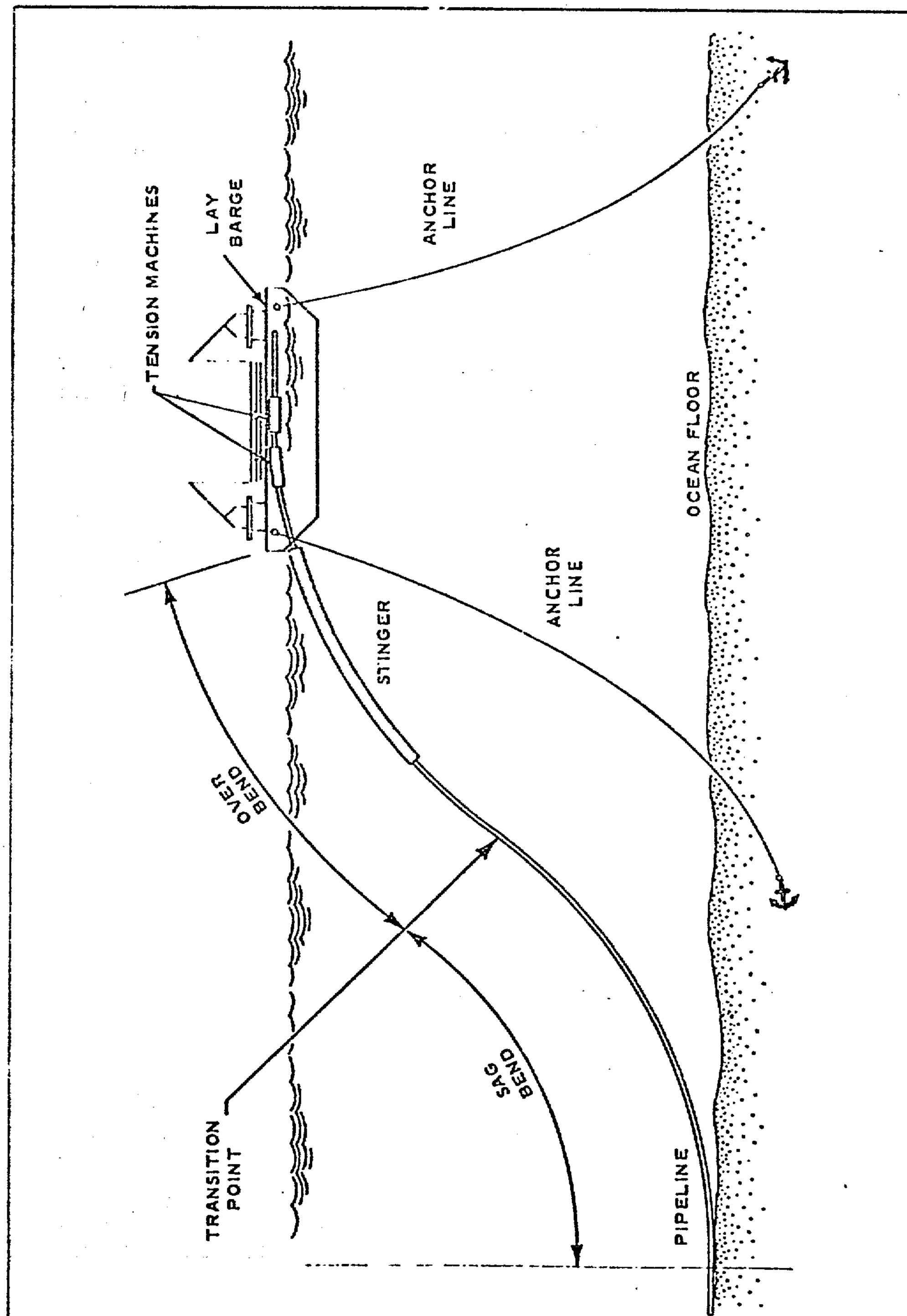
The construction of a man-made offshore island port is considered impractical due to the water depth, earthquake hazard, and bottom conditions. Conventional Buoy Moors (CBM) are not used because they hold a ship in a fixed position, rather than permit the vessel to assume the best heading based on prevailing wind and waves, as with the SPM. In an exposed location on the Alaskan OCS, the swivel feature becomes imperative for survival.

(2) Pipeline Transportation

Pipelines were limited to offshore routes for the Gulf of Alaska study. Onshore routes would encounter many obstacles, including glaciers, mountains, landslide areas, a wide river delta, and possible land use restrictions. In addition, poor ocean floor soil stability between Kayak Island and the Hinchenbrook Entrance prevents bringing a pipeline ashore in that area.

The most common method of offshore pipelaying is the use of the lay barge. A typical lay barge configuration is shown in Figure II-1. Pipe is normally delivered to the lay barge in 40-foot sections, although some new lay barges are capable of handling 80-foot sections of pipe. The barge is divided into several stations. At the first station, the new section is aligned to the previous installed length and prepared for welding. When the two sections have been welded, they are then X-rayed to establish the integrity of the welds.

FIGURE II-1
Pipeline Lay Barge



Once the welds are proven satisfactory, a protective coating of hot asphalt known as a "field joint" is applied. The entire pipe section is then coated with a preservative and predetermined thickness of concrete mesh. The concrete serves the dual purpose of providing negative buoyancy during installation and stability against wave action after the line is installed and lying on the ocean bottom. Frequently the pipe sections are pre-coated onshore and the joints finished aboard the barge.

When the above process is completed, the barge, which is being held in position by anchors, is moved ahead and the new section of pipe is lowered off the stern of the barge. To support the pipe and reduce the risk of buckling due to excessive bending stresses, a device known as a "stinger" extends from the stern of the barge and supports the pipe as it sinks to the bottom, or to a point where the pipe is capable of self-support. It is obvious, therefore, that pipelaying becomes increasingly complex as water depth increases.

In depths where stinger support of the pipe is not sufficient, the use of a tension device enables pipelines to be constructed. By applying axial tensile force, bending stress is controlled and the risk of buckling reduced.

The new BAR 347, scheduled for delivery in mid-1976, utilizes three tensioning devices to eliminate the need for a stinger. This barge will be able to lay 36" diameter pipe in water 200 fathoms deep.

Pipelines are often buried three to ten feet to protect them from damage due to external forces. In the past this has been accomplished in relatively shallow depths, approximately two hundred feet or less, by use of a "bury barge." The barge is equipped with high pressure water pumps providing jetting action to cut the sea floor beneath the pipe. The jet nozzles are mounted on a sled which straddles the pipe after it is laid on the sea floor.

Recently, the Santa Fe International Corporation placed an order with a Dutch shipyard for a deep water pipeline bury barge with capabilities of operating in depths up to 160 fathoms. The barge, which is scheduled for delivery in mid-1976, will be able to excavate a trench seven feet deep on a single pass under favorable soil conditions.

Since pipeline routes in the Gulf of Alaska are located in water less than two hundred fathoms deep, present technology is sufficient to make this a feasible transportation mode.

2. STORAGE ALTERNATIVES

Storage alternatives are divided into three categories; ashore storage tanks, floating storage tanks, and ocean floor storage tanks. The remainder of this section is devoted to a description of current technology for each storage category.

(1) Ashore Storage

Cylindrical tanks are the most conventional form of storage. These afford a simple, reliable means for storing large quantities of oil. This type of tank will be used at the southern terminal of the Trans-Alaska Pipeline in Valdez. Each of the Valdez tanks will hold 510,000 barrels of crude oil. Their design could readily be adopted for use near the Gulf of Alaska lease area.

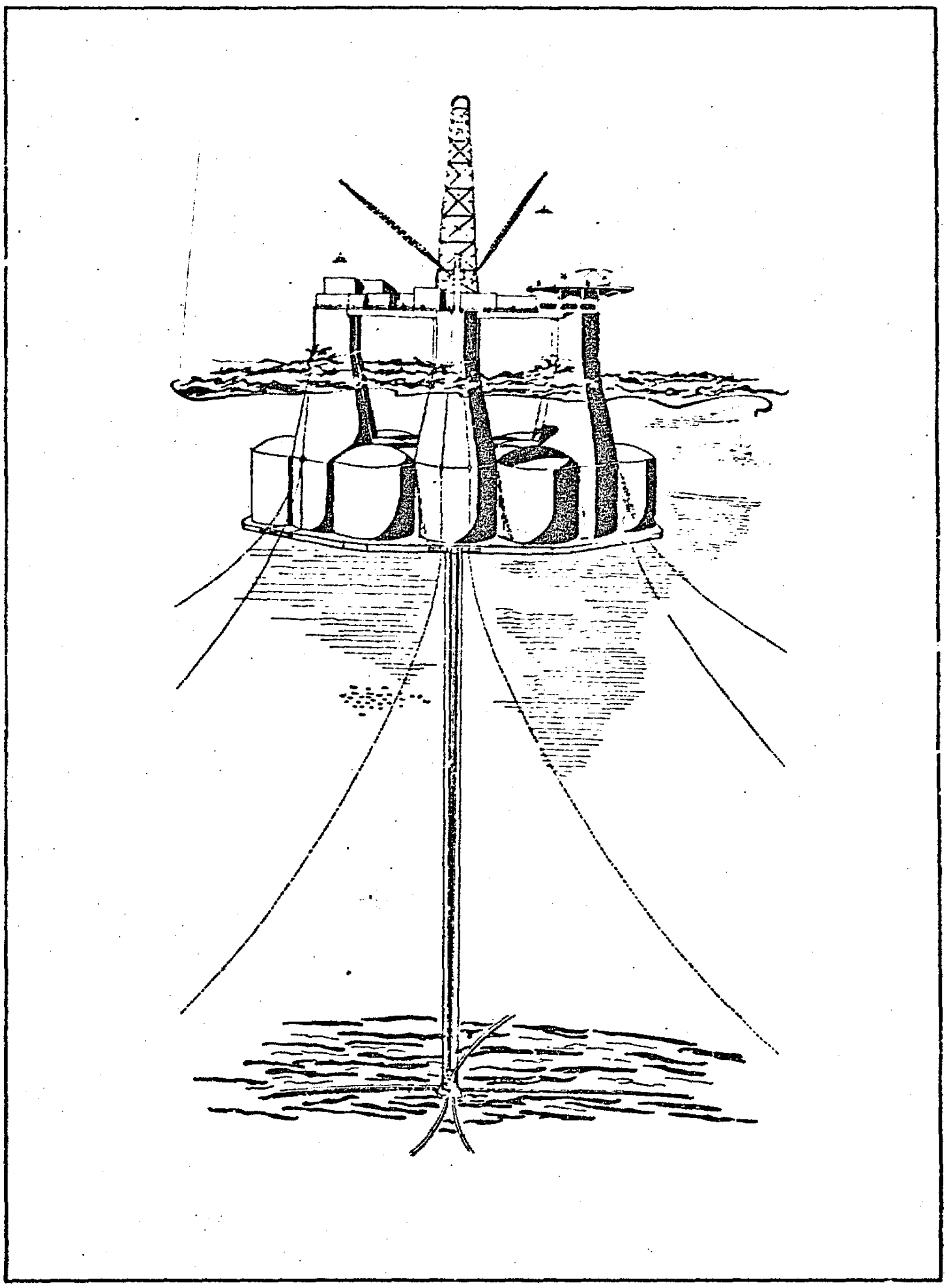
(2) Floating Storage

Floating storage in the Gulf of Alaska will be limited to the newer concrete structures. Barges and converted tankers are not suitable for use in the Gulf due to the severe storms in this area. The concrete tanks are designed to minimize the effects of large waves.

An example of this type of structure is the Shell Spar buoy. It is a vertical spar capable of storing 300,000 barrels of oil, and has been installed in the North Sea. The Spar also functions as an SPM, which introduces the possibility of oil spills in a collision. For this study, floating storage is assumed to require a separate SPM for mooring tankers.

Another form of floating storage, presently undergoing model tests, is the Conprod integrated production and storage platform shown in Figure II-2. The subsurface oil storage capacity of 500,000 barrels would not be damaged by tankers in the event of a collision and provides a stable platform for production equipment.

FIGURE II-2
Conprod Floating Production
and Storage Platform



SOURCE: OCEAN INDUSTRY, MAY, 1975

Oil stored in the tanks would be loaded into tankers through a separate SPM. Many designs have been proposed for floating storage facilities and most should satisfy the assumptions made in the risk and cost analyses performed during this study and documented in the next two chapters. The examples cited are merely to aid the reader and do not constitute the recommendation of a specific design.

(3) <u>Ocean Floor Storage</u>

This group consists of large concrete storage tanks, of various geometries, resting on the ocean floor. The most advanced of these are the CONDEEP production platforms. The CONDEEP has three circular towers supporting a massive platform, and has one million barrels of storage capacity in its base. Two such units were successfully installed in 1975.

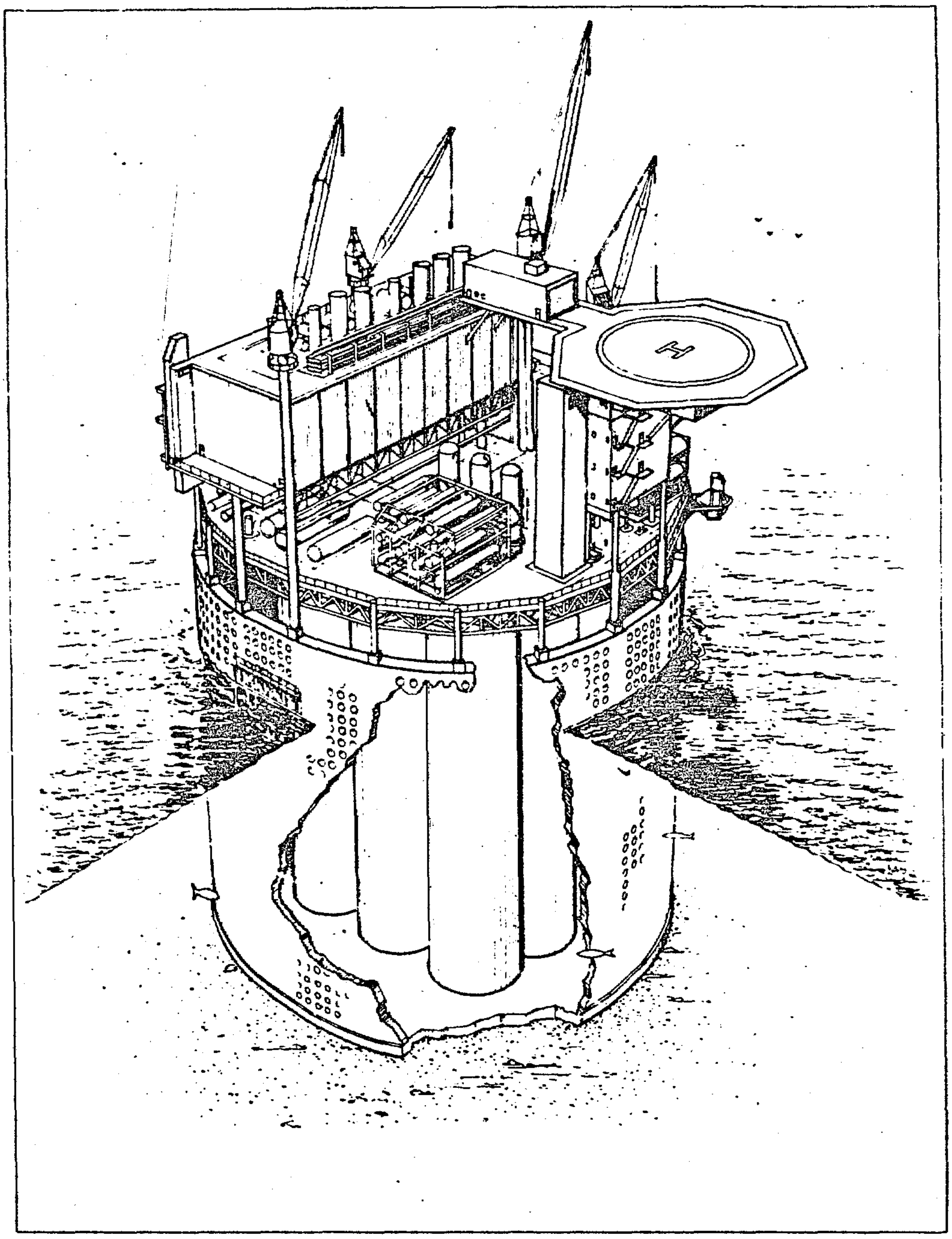
Another example of ocean floor storage is the Phillips Ekofisk tank in the North Sea, shown in Figure II-3. It has one million barrels of storage capacity in nine central compartments. The tanks are protected from heavy seas by a perforated outer wall. This facility has weathered one very large storm. As was the case with floating storage, numerous design variations are possible, but most should have the same basic characteristics considered in the cost and risk analyses.

3. CANDIDATE TRANSPORTATION AND STORAGE SYSTEMS

It is not contemplated that oil produced in the Gulf of Alaska will be refined or consumed in Alaska or adjoining parts of Canada, nor is it anticipated that such oil will be moved to refining or consuming areas overland. This implies that Gulf of Alaska oil will be transported by tanker over sea routes to locations as distant as the U.S. west coast. Since all sea routes of interest pass near the lease area, the logical boundary for the subsystem within which alternatives are to be analyzed is represented on the downstream side by oil on board a tanker underway to a refining or consuming destination.

The upstream boundary of the transportation subsystem is the point of physical transfer or change in custody from producing facilities to the transporter. However, the use of tankers implies a

FIGURE II-3
Ekofisk Ocean Floor
Storage Tank



Source: CEQ Report, 1974

requirement for substantial offshore storage capability that is not required if pipelines are employed for transfer to shore. Costs and spill risks associated with offshore storage thus must be considered in evaluating tanker alternatives, and such storage facilities effectively become part of the tanker transportation subsystem. Hence, integrated transportation and storage systems were designed for each hypothetical production site.

Three general concepts of transportation and storage systems were utilized; tanker transshipment, pipeline transshipment, and direct shipment. Each of these concepts is outlined below:

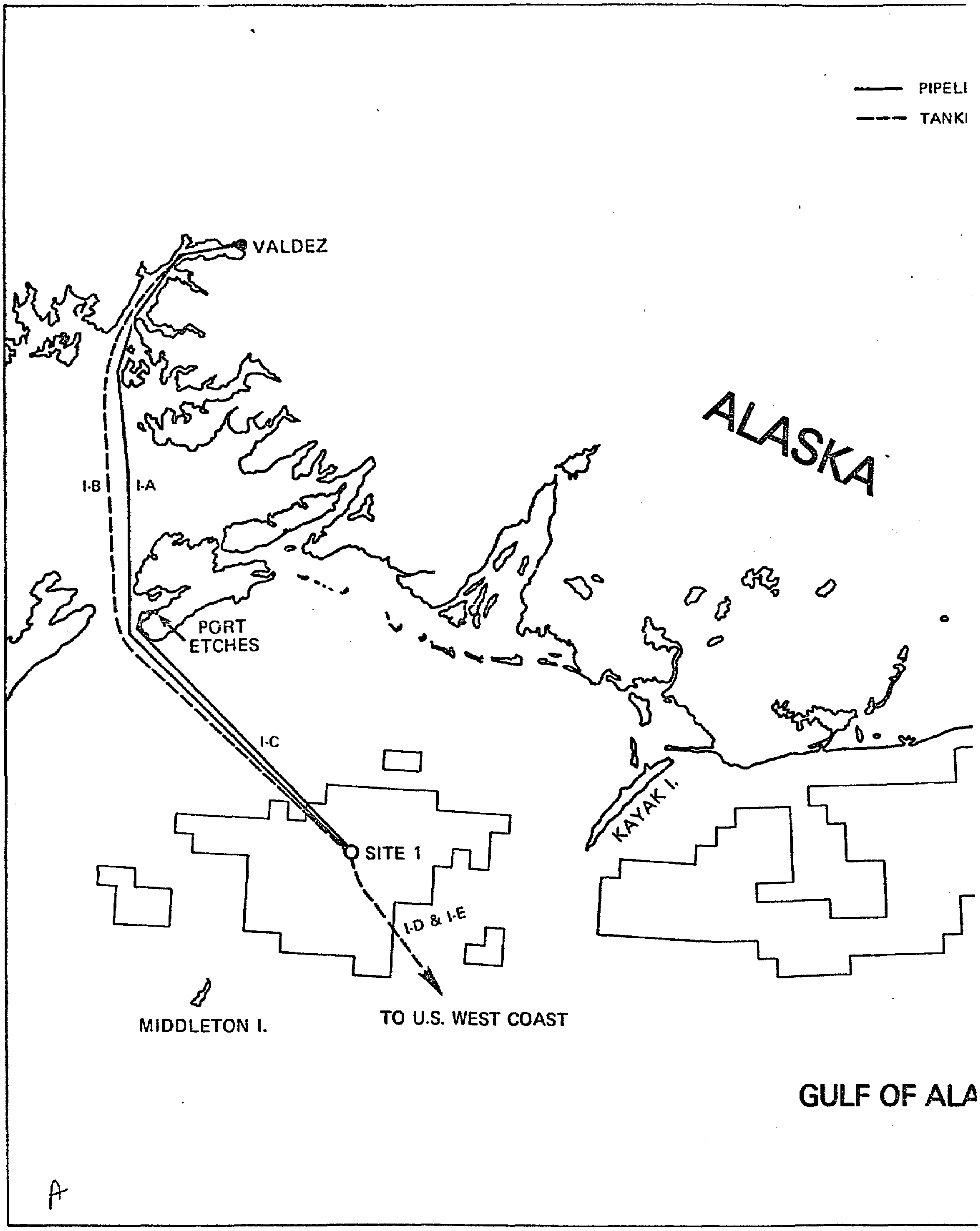
- <u>Tanker transshipment</u> — Offshore oil is stored temporarily at the production site, where it is picked up by a small, short-haul tanker. This tanker carries the oil to a port facility near the Gulf, and offloads to shore storage. Next, the oil is loaded aboard a 90,000 dwt tanker for shipment to the U.S. west coast.

- <u>Pipeline transshipment</u> — A pipeline links the production site to a shore port facility. Oil is produced offshore and pumped through the pipeline to ashore storage at the port, then carried to the U.S. west coast by a 90,000 dwt tanker.

- <u>Direct shipment</u> — Oil produced and stored offshore is transported directly to the U.S. west coast by a 90,000 dwt tanker.

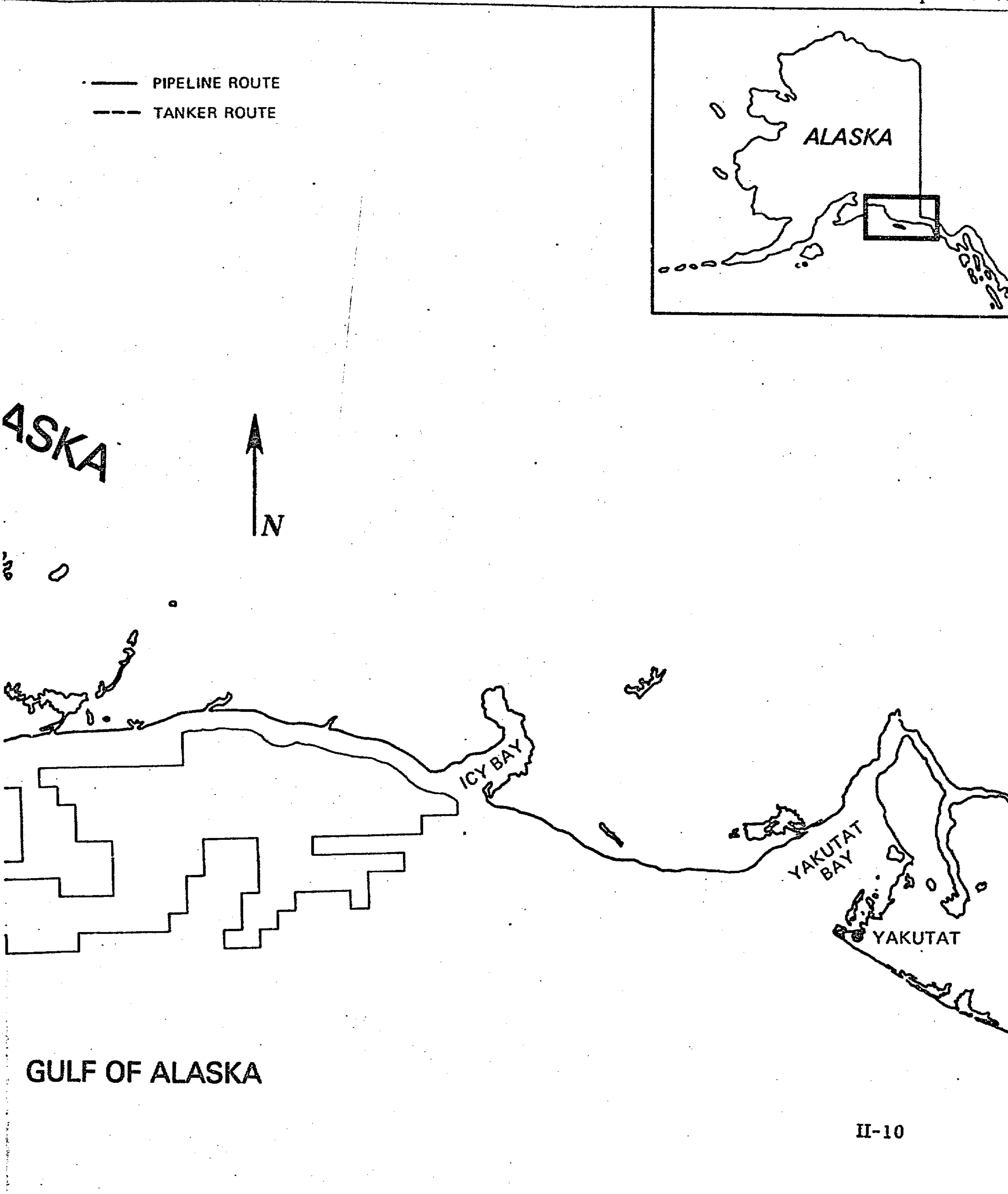
A 90,000 dwt tanker was selected for long distance shipping because it is the average size presently under construction for the Alaskan trade. It is also the largest tanker which can enter U.S. west coast ports without lightering; which is transferring some of its cargo to a smaller vessel. To investigate the impact of utilizing a larger tanker on this route, a risk sensitivity analysis was performed and is described in Chapter 4.

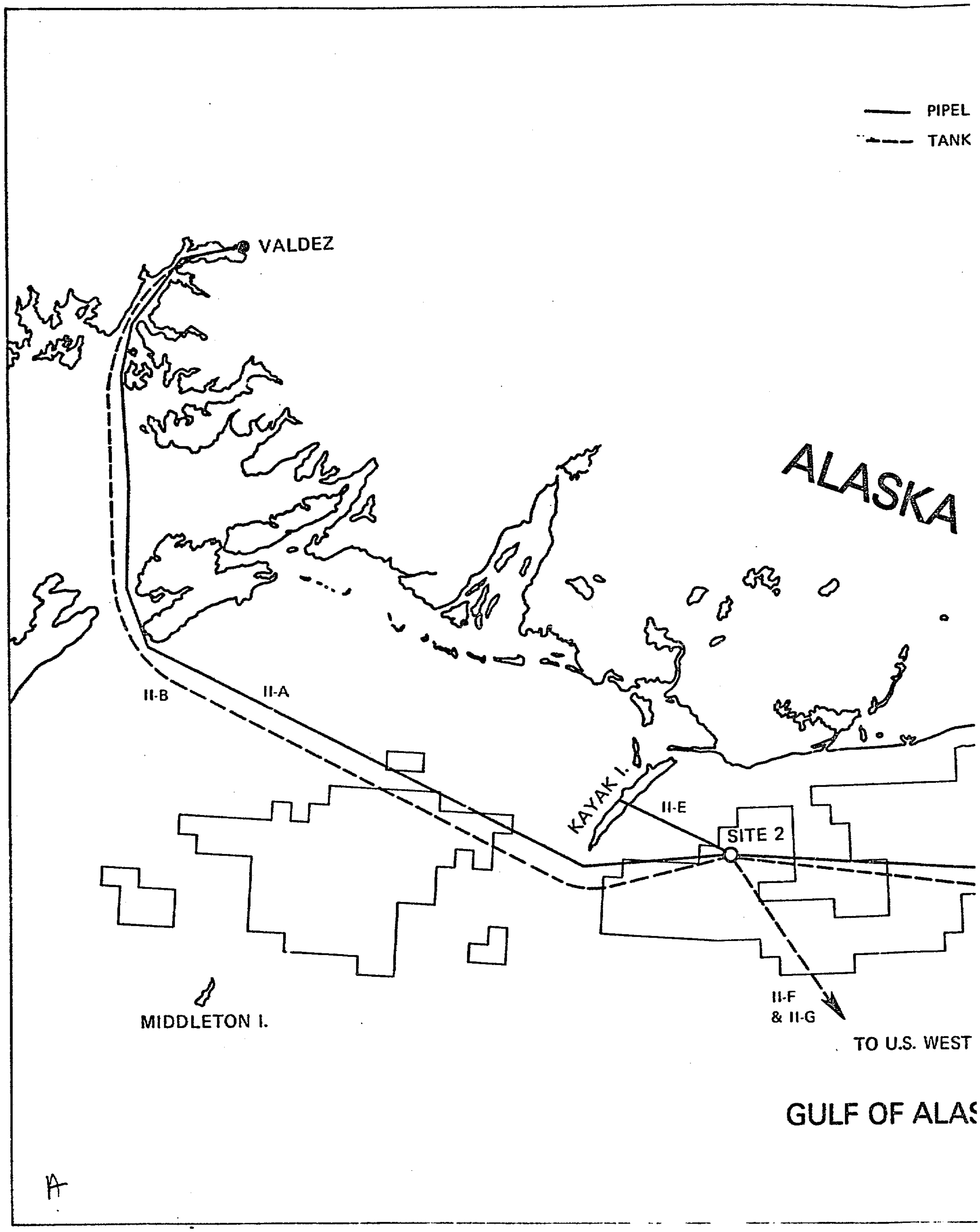
Tanker and pipeline routes for each of the four hypothetical production sites are shown in Figures II-4 through II-7. While there are numerous possible routes, the ones selected for this study are sufficiently representative for an analysis of the transportation concepts, but should not be construed as a recommendation of a specific route. The elements comprising each transportation and storage system are identified in Table II-1. As an example of how to read the table, Alternate 1-B uses floating storage at the production site. Oil is transferred



PIPELI
TANKI
VALDEZ
ALASKA
I-B
I-A
PORT ETCHES
I-C
SITE 1
KAYAK I.
I-D & I-E
MIDDLETON I.
TO U.S. WEST COAST
GULF OF ALA
A

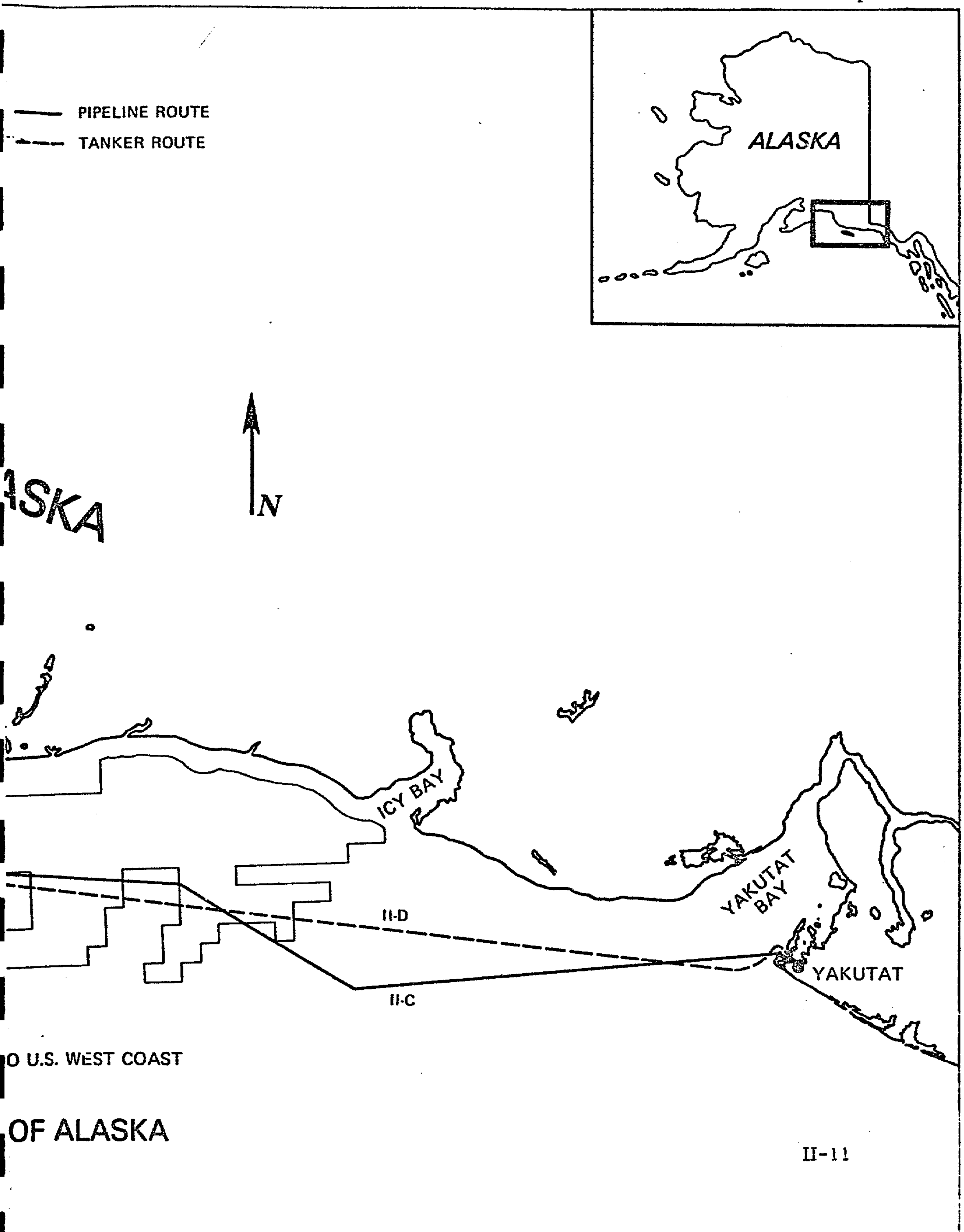
FIGURE II-4
Site 1 Tanker and Pipeline Route



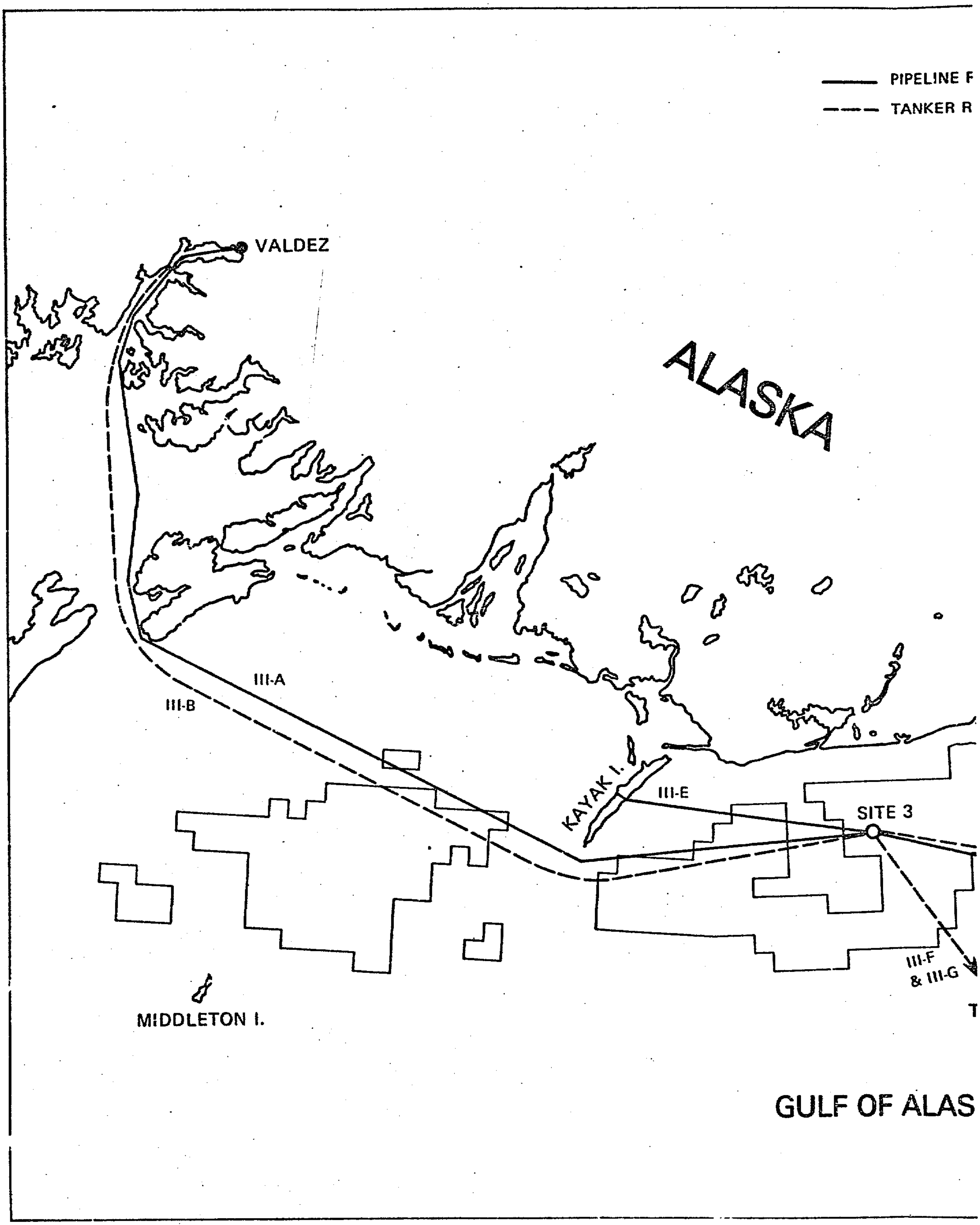


PIPEL
TANK
VALDEZ
ALASKA
II-B
II-A
KAYAK I.
II-E
SITE 2
MIDDLETON I.
II-F
& II-G
TO U.S. WEST
GULF OF ALAS
A

FIGURE II-5
Site 2 Tanker and Pipeline Routes



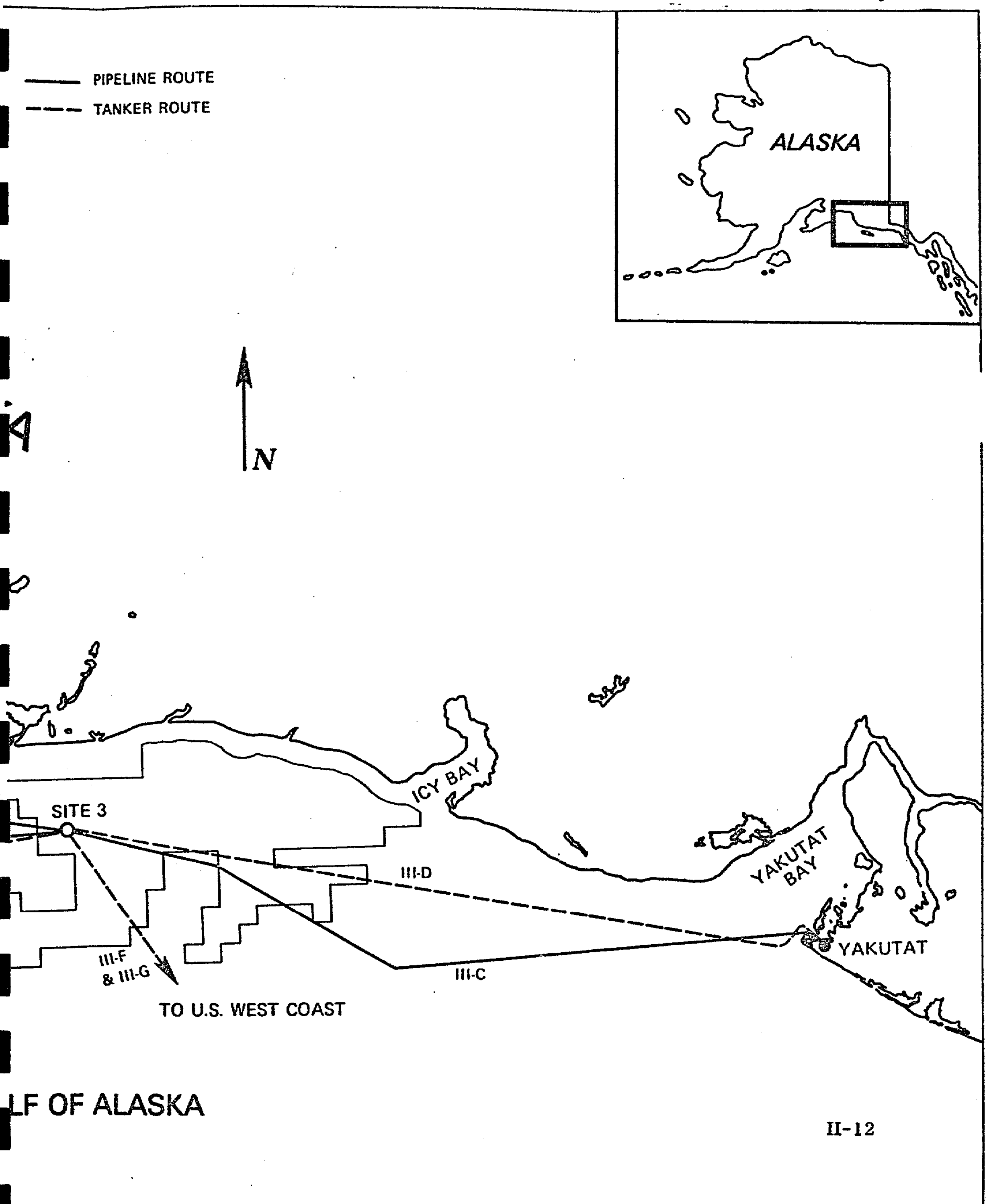
B

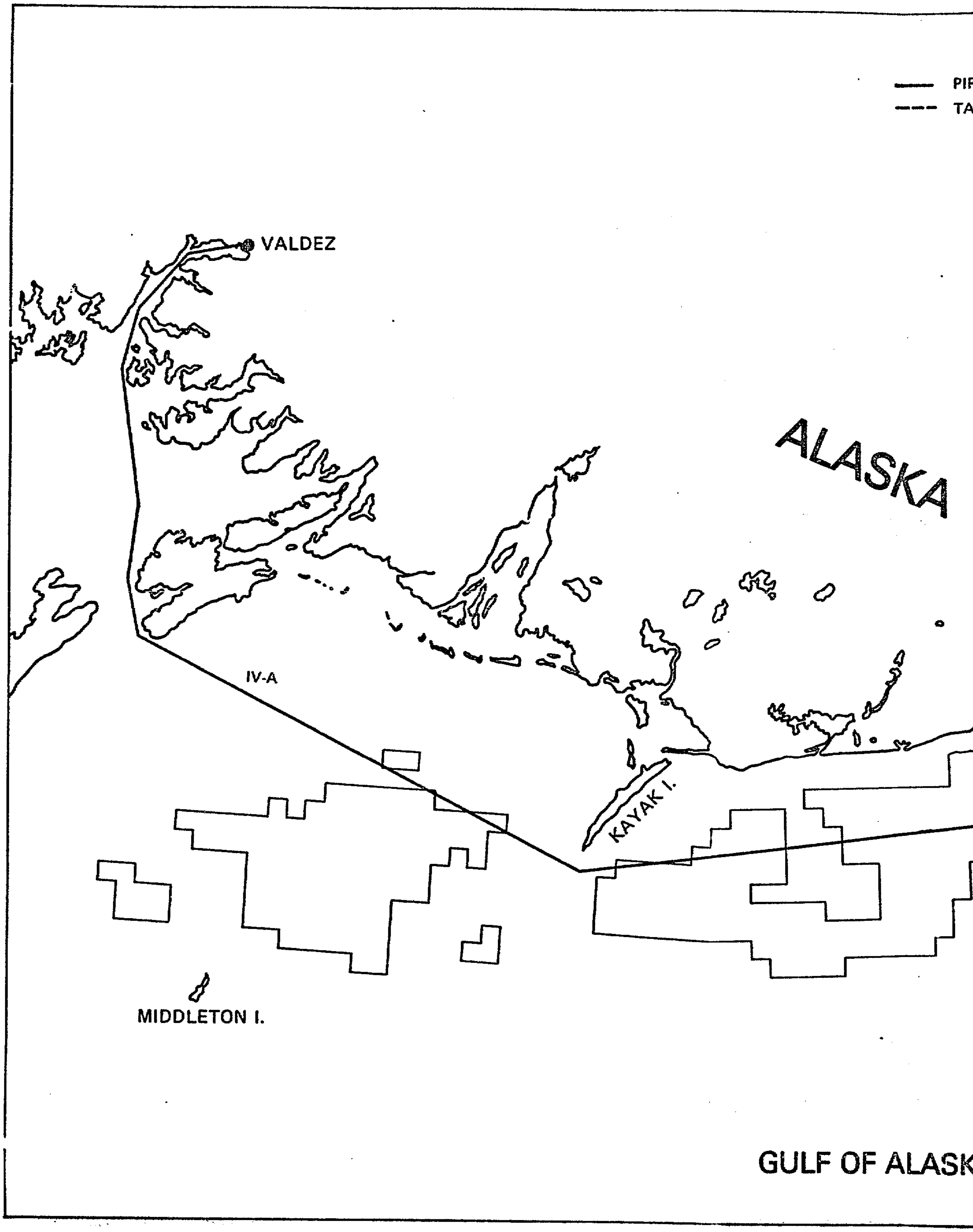


PIPELINE F
TANKER R
VALDEZ
ALASKA
III-A
III-B
KAYAK I.
III-E
SITE 3
III-F
& III-G
T
MIDDLETON I.
GULF OF ALAS

A

FIGURE II-6
Site 3 Tanker and Pipeline Routes





A

FIGURE II-7
Site 4 Tanker and Pipeline Routes

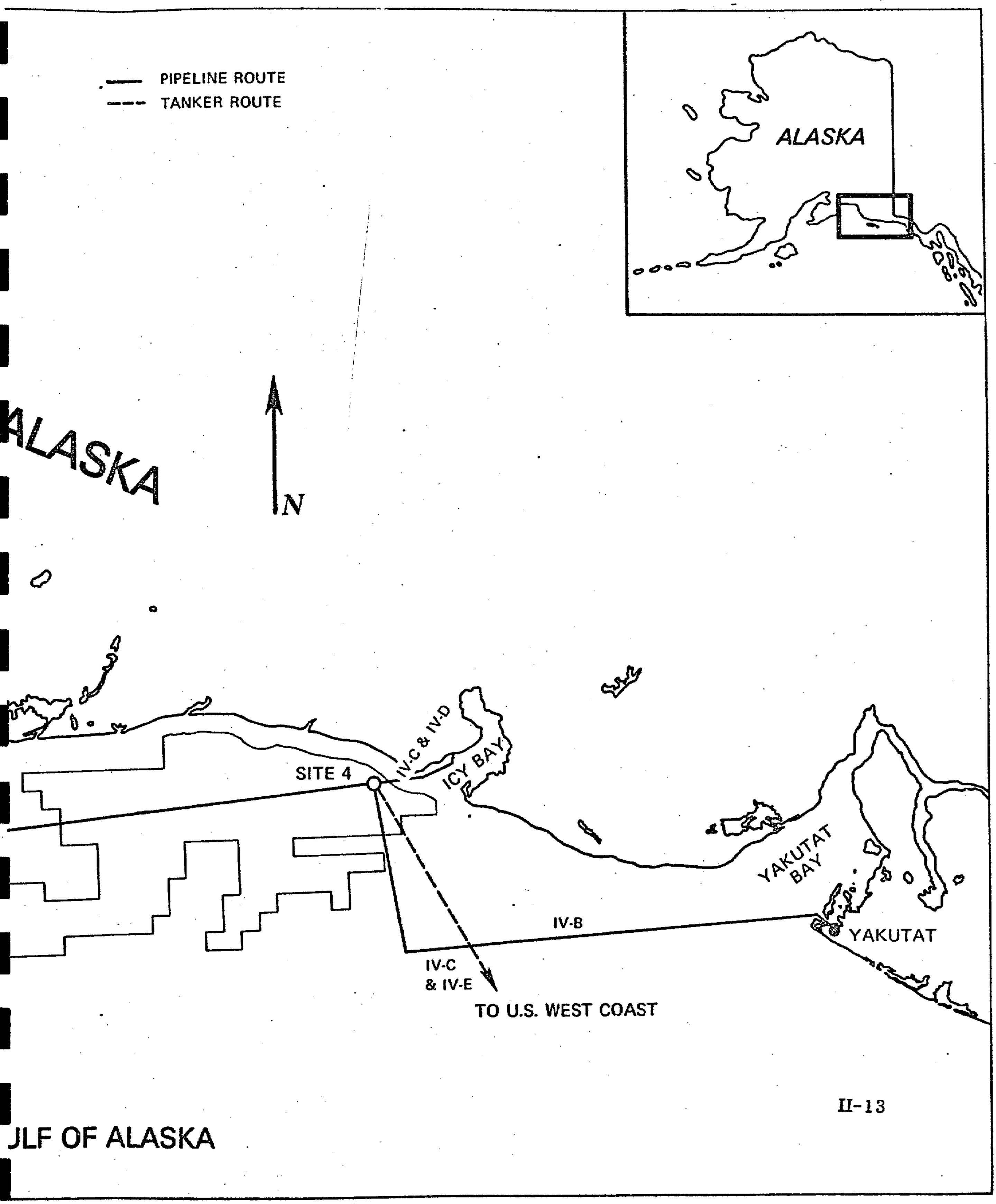


Table II-1
Transportation and Storage Systems

PRODUCTION SITE				INTERMEDIATE TRANSPORTATION		INTERMEDIATE STORAGE		FINAL TRANSPORTATION	
SITE	ALTERNATE	STORAGE	MOORING	MODE	DESTINATION	STORAGE	MOORING	MODE	DESTINATION
1	A	–	–	PIPELINE	VALDEZ	ASHORE	DOCK	TANKER	U.S. WEST COAST
	B	FLOATING	SPM	TANKER	VALDEZ	ASHORE	DOCK	TANKER	U.S. WEST COAST
	C	–	–	PIPELINE	PORT ETCHES	ASHORE	DOCK	TANKER	U.S. WEST COAST
	D	FLOATING	SPM	–	–	–	–	TANKER	U.S. WEST COAST
	E	OCEAN FLOOR	SPM	–	–	–	–	TANKER	U.S. WEST COAST
2	A	–	–	PIPELINE	VALDEZ	ASHORE	DOCK	TANKER	U.S. WEST COAST
	B	FLOATING	SPM	TANKER	VALDEZ	ASHORE	DOCK	TANKER	U.S. WEST COAST
	C	–	–	PIPELINE	YAKUTAT	ASHORE	DOCK	TANKER	U.S. WEST COAST
	D	FLOATING	SPM	TANKER	YAKUTAT	ASHORE	DOCK	TANKER	U.S. WEST COAST
	E	–	–	PIPELINE	KAYAK ISLAND	ASHORE	SPM	TANKER	U.S. WEST COAST
	F	FLOATING	SPM	–	–	–	–	TANKER	U.S. WEST COAST
	G	OCEAN FLOOR	SPM	–	–	–	–	TANKER	U.S. WEST COAST
3	A	–	–	PIPELINE	VALDEZ	ASHORE	DOCK	TANKER	U.S. WEST COAST
	B	FLOATING	SPM	TANKER	VALDEZ	ASHORE	DOCK	TANKER	U.S. WEST COAST
	C	–	–	PIPELINE	YAKUTAT	ASHORE	DOCK	TANKER	U.S. WEST COAST
	D	FLOATING	SPM	TANKER	YAKUTAT	ASHORE	DOCK	TANKER	U.S. WEST COAST
	E	–	–	PIPELINE	KAYAK ISLAND	ASHORE	SPM	TANKER	U.S. WEST COAST
	F	FLOATING	SPM	–	–	–	–	TANKER	U.S. WEST COAST
	G	OCEAN FLOOR	SPM	–	–	–	–	TANKER	U.S. WEST COAST
4	A	–	–	PIPELINE	VALDEZ	ASHORE	DOCK	TANKER	U.S. WEST COAST
	B	–	–	PIPELINE	YAKUTAT	ASHORE	DOCK	TANKER	U.S. WEST COAST
	C	ASHORE	SPM	PIPELINE	ICY BAY	–	–	TANKER	U.S. WEST COAST
	D	–	–	PIPELINE	ICY BAY	ASHORE	DOCK	TANKER	U.S. WEST COAST
	E	OCEAN FLOOR	SPM	–	–	–	–	TANKER	U.S. WEST COAST

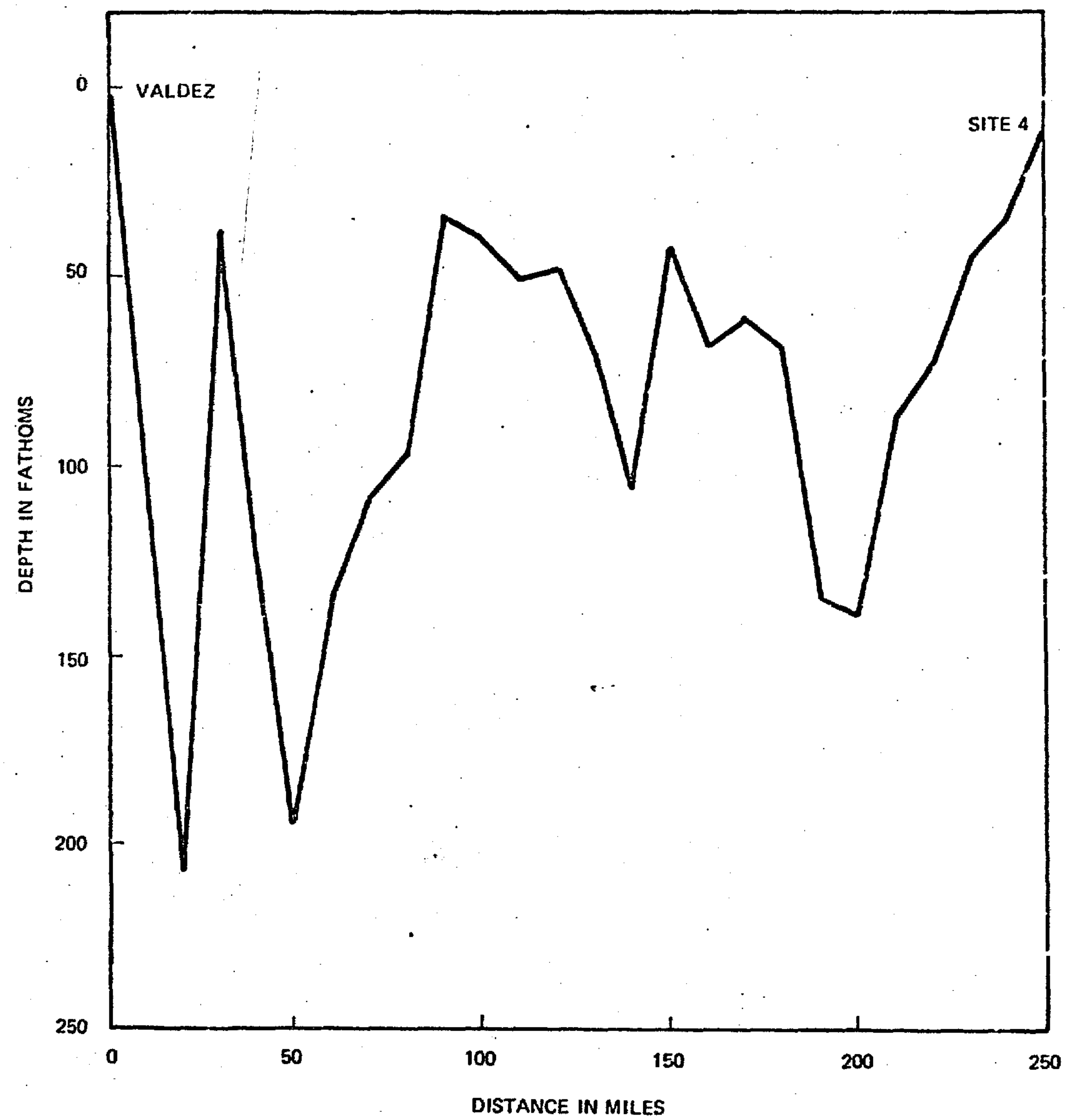
from this storage through an SPM to a tanker and carried to Valdez, where it is offloaded at a conventional dock into ashore storage. Next, the oil is loaded onto a long-haul tanker and carried to the U.S. west coast.

Floating storage cannot be used at Site 4 since the water is too shallow. However, the near proximity of land made it attractive to use a pipeline to ashore storage, and, through the same pipeline, load tankers at the production site with a SPM. While storage is being drawn down, the platform would produce directly into the tanker.

A depth profile for the longest pipeline, from Valdez to Site 4, is shown in Figure II-8. These depths are typical of the area, and are within the capability of present pipelaying technology.

In the next chapter an analysis of the economic characteristics of these alternatives is presented.

FIGURE II-8
Valdez to Site 4
Pipeline Depth Profile



III. ECONOMIC ANALYSIS

1. INTRODUCTION

The economics of Outer Continental Shelf (OCS) oil transport and storage systems are dependent upon four conditions:

- Amount of recoverable reserves
- Distance from the collection point to onshore terminal
- Depth of water in which the reserves lie and depths along the route from the collection point to onshore terminal
- Distance from Gulf of Alaska to final destination.

The costs of the surface marine, pipeline, and storage systems will be influenced by the above factors.

The amount of recoverable reserves will determine the production rate of the wells which, in turn, will affect the:

- Capacity of the tanker required
- Capacity of storage facilities required
- Diameter of pipeline required.

The distance from collection point to the onshore terminal will determine:

- Size and cost of the required tankers
- Length of the pipeline system
- Capacity of the storage system.

Water depth will have an affect on:

- Installation costs of mooring systems
- Material and construction costs for the pipeline
- Construction and installation costs for storage.

The distance from the Gulf of Alaska to U.S. west coast ports will increase transportation costs, as the oil is neither refined nor consumed in the Gulf area. The total cost of this trip was not included in the economic analysis as each alternate requires the same final tanker transportation and inclusion of this trip would merely increase the cost of each system by a similar increment. However, large tankers calling at the Valdez port travel a slightly longer distance, and this marginal cost difference is included in the life cycle cost of alternatives utilizing the port.

2. TANKER SIMULATION MODEL

The climatological conditions described in Chapter I could have a severe impact on tanker operations in the lease area. Since the transit time and size of a tanker dictate the storage capacity needed, the effects of weather must be given careful consideration. Three parameters were identified as being critical for tanker operation; wind, fog, and sea state. Each of the three may occur at different levels of intensity, or in a variety of combinations, and the impact is dependent upon tanker routing. Obviously, the hazards associated with wind and fog will hinder tanker movements more in a narrow passage than in relatively open waters.

To cope with the magnitude of the problem and the stochastic nature of climatological events, a Markov process computer simulation model was constructed. The model computes approximate transit time and storage capacity based on tanker size, route description, and a matrix of weather occurrence probabilities. Simulations were made for several tanker sizes to optimize the relationship between tanker size and storage capacity. When larger tankers are used, fewer of them are needed to transport a fixed production rate of oil. This results in more time between tanker arrivals and an increase in storage capacity to contain the oil produced while the tanker is away. The savings associated with fewer tankers will be in balance with the cost of additional storage at the optimum. The optimized values were then utilized in the economic and risk analyses. A description of the model is contained in Appendix A. Tanker and storage capacities, together with pipeline sizes, are shown in Tables III-1 through III-6 for six different reserve levels.

Table III-1
Transportation and Storage Requirements
for 25 Million Barrel Reserve

Alternate*	Production Site Storage (bbls)	Shuttle Tanker** Capacity (dwt)	Pipeline Size (in.)
1 - A	-	-	6
1 - B	21,100	2,800	-
1 - C	-	-	6
1 - D	34,000	-	-
1 - E	34,000	-	-
2 - A	-	-	8
2 - B	21,100	2,800	-
2 - C	-	-	8
2 - D	22,400	2,500	-
2 - E	-	-	6
2 - F	34,000	-	-
2 - G	34,000	-	-
3 - A	-	-	8
3 - B	21,100	2,800	-
3 - C	-	-	8
3 - D	22,400	2,500	-
3 - E	-	-	6
3 - F	34,000	-	-
3 - G	34,000	-	-
4 - A	-	-	8
4 - B	-	-	6
4 - C	34,000	-	6
4 - D	-	-	6
4 - E	34,000	-	-

* Alternates are defined in Chapter II.

** One tanker is required.

Note: Intermediate storage capacity ashore, if utilized, is 34 thousand barrels. All alternates use a 90,000 dwt tanker for transportation to the U.S. west coast.

Table III-2
Transportation and Storage Requirements
for 100 Million Barrel Reserve

Alternate*	Production Site Storage (bbls)	Shuttle Tanker** Capacity (dwt)	Pipeline Size (in.)
1 - A	-	-	12
1 - B	84,400	11,200	-
1 - C	-	-	10
1 - D	137,000	-	-
1 - E	137,000	-	-
2 - A	-	-	12
2 - B	84,400	11,200	-
2 - C	-	-	12
2 - D	89,600	10,000	-
2 - E	-	-	8
2 - F	137,000	-	-
2 - G	137,000	-	-
3 - A	-	-	12
3 - B	84,400	11,200	-
3 - C	-	-	10
3 - D	89,600	10,000	-
3 - E	-	-	10
3 - F	137,000	-	-
3 - G	137,000	-	-
4 - A	-	-	12
4 - B	-	-	10
4 - C	137,000	-	8
4 - D	-	-	8
4 - E	137,000	-	-

* Alternates are described in Chapter II.

** One tanker is required.

Note: Intermediate storage capacity ashore, if utilized, is 137 thousand barrels. All alternates use a 90,000 dwt tanker for transportation to the U.S. west coast.

Table III-3
Transportation and Storage Requirements
for 500 Million Barrel Reserve

Alternate*	Production Site Storage (bbls)	Shuttle Tanker** Capacity (dwt)	Pipeline Size (in.)
1 - A	-	-	20
1 - B	250,000	28,000	-
1 - C	-	-	18
1 - D	685,000	-	-
1 - E	685,000	-	-
2 - A	-	-	22
2 - B	250,000	28,000	-
2 - C	-	-	22
2 - D	308,000	25,000	-
2 - E	-	-	14
2 - F	685,000	-	-
2 - G	685,000	-	-
3 - A	-	-	22
3 - B	250,000	28,000	-
3 - C	-	-	20
3 - D	308,000	25,000	-
3 - E	-	-	16
3 - F	685,000	-	-
3 - G	685,000	-	-
4 - A	-	-	20
4 - B	-	-	20
4 - C	685,000	-	14
4 - D	-	-	14
4 - E	685,000	-	-

* Alternates are defined in Chapter II.

** Two tankers are required.

Note: Intermediate storage capacity ashore, if utilized, is 685 thousand barrels. All alternates use a 90,000 dwt tanker for transportation to the U.S. west coast.

Table III-4
Transportation and Storage Requirements
for 1,000 Million Barrel Reserve

Alternate*	Production Site Storage (bbls)	Shuttle Tanker** Capacity (dwt)	Pipeline Size (in.)
1 - A	-	-	26
1 - B	482,000	37,000	-
1 - C	-	-	22
1 - D	1,370,000	-	-
1 - E	1,370,000	-	-
2 - A	-	-	24
2 - B	482,000	37,000	-
2 - C	-	-	24
2 - D	582,000	35,000	-
2 - E	-	-	18
2 - F	1,370,000	-	-
2 - G	1,370,000	-	-
3 - A	-	-	24
3 - B	482,000	37,000	-
3 - C	-	-	26
3 - D	582,000	35,000	-
3 - E	-	-	20
3 - F	1,370,000	-	-
3 - G	1,370,000	-	-
4 - A	-	-	24
4 - B	-	-	24
4 - C	1,370,000	-	18
4 - D	-	-	18
4 - E	1,370,000	-	-

* Alternates are defined in Chapter II.

** Three tankers are required.

Note: Intermediate storage capacity ashore, if utilized, is 1.37 million barrels. All alternates use a 90,000 dwt tanker for transportation to the U.S. west coast.

Table III-5
Transportation and Storage Requirements
for 1, 500 Million Barrel Reserve

Alternate*	Production Site Storage (bbls)	Shuttle Tanker** Capacity (dwt)	Pipeline Size (in.)
1 - A	-	-	26
1 - B	735,000	33,700	-
1 - C	-	-	26
1 - D	2,055,000	-	-
1 - E	2,055,000	-	-
2 - A	-	-	28
2 - B	735,000	33,700	-
2 - C	-	-	28
2 - D	888,000	32,200	-
2 - E	-	-	22
2 - F	2,055,000	-	-
2 - G	2,055,000	-	-
3 - A	-	-	26
3 - B	735,000	33,700	-
3 - C	-	-	26
3 - D	888,000	32,200	-
3 - E	-	-	24
3 - F	2,055,000	-	-
3 - G	2,055,000	-	-
4 - A	-	-	26
4 - B	-	-	28
4 - C	2,055,000	-	22
4 - D	-	-	22
4 - E	2,055,000	-	-

* Alternates are described in Chapter II.

** Five tankers are required.

Note: Intermediate storage capacity ashore, if utilized, is 2.055 million barrels. All alternates use a 90,000 dwt tanker for transportation to the U.S. west coast.

Table III-6
Transportation and Storage Requirements
for 2,000 Million Barrel Reserve

Alternate*	Production Site Storage (bbls)	Shuttle Tanker** Capacity (dwt)	Pipeline Size (in.)
1 - A	-	-	28
1 - B	964,000	37,000	-
1 - C	-	-	28
1 - D	2,740,000	-	-
1 - E	2,740,000	-	-
2 - A	-	-	28
2 - B	964,000	37,000	-
2 - C	-	-	28
2 - D	1,164,000	35,000	-
2 - E	-	-	24
2 - F	2,740,000	-	-
2 - G	2,740,000	-	-
3 - A	-	-	28
3 - B	964,000	37,000	-
3 - C	-	-	30
3 - D	1,164,000	35,000	-
3 - E	-	-	26
3 - F	2,740,000	-	-
3 - G	2,740,000	-	-
4 - A	-	-	28
4 - B	-	-	30
4 - C	2,740,000	-	24
4 - D	-	-	24
4 - E	2,740,000	-	-

* Alternates are defined in Chapter II.

** Six tankers are required.

Note: Intermediate storage capacity ashore, if utilized, is 2.74 million barrels. All alternates use a 90,000 dwt tanker for transportation to the U.S. west coast.

3. ECONOMIC ANALYSIS METHODOLOGY

The methodology employed in this economic analysis is detailed in Appendix B. The costs are based on data obtained from maritime reports and publications, pipeline construction manuals, and interviews with marine transportation analysts and pipeline designers. Although inflation factors were considered when calculating life-cycle costs, oil transportation and storage expenses can be significantly more volatile than the general economy.

Capital costs for the tanker system include the short-haul tanker investment cost, and the expense of mooring and storage facilities. Tanker operating costs are comprised of fuel costs, wages, maintenance and insurance. The life-cycle cost of various tanker sizes is shown in Figure III-1. The marginal cost for large tankers includes charter and fuel costs. A charter rate of $8 per ton per month was used.

In the case of the pipeline, capital costs are those incurred when constructing the line and any necessary pumping stations, plus storage facilities and moors for the long-haul tanker. Construction costs per mile of pipeline are contained in Table III-7. Operational costs primarily include maintenance and monitoring expenses, and are estimated to be four percent* of capital costs. The cost of ashore storage was based on a survey of recent construction. In the lower 48 states, steel tanks cost approximately $5 per barrel of storage capacity, including site preparation. It was estimated the same tanks would cost one hundred percent more to construct in Alaska, due to the remote location. The cost used in the analysis was $10 per barrel of capacity.

Floating and ocean floor storage costs were approximated by taking the cost of new production and storage platforms described in Chapter II, and subtracting the cost of a platform without storage. The marginal cost of storage was calculated on a per barrel basis, and was found to be $50 per barrel for floating storage and $30 per barrel for ocean floor storage. This represents the cost of adding storage to a platform, and is a reasonable approach since a production platform must be provided in any case.

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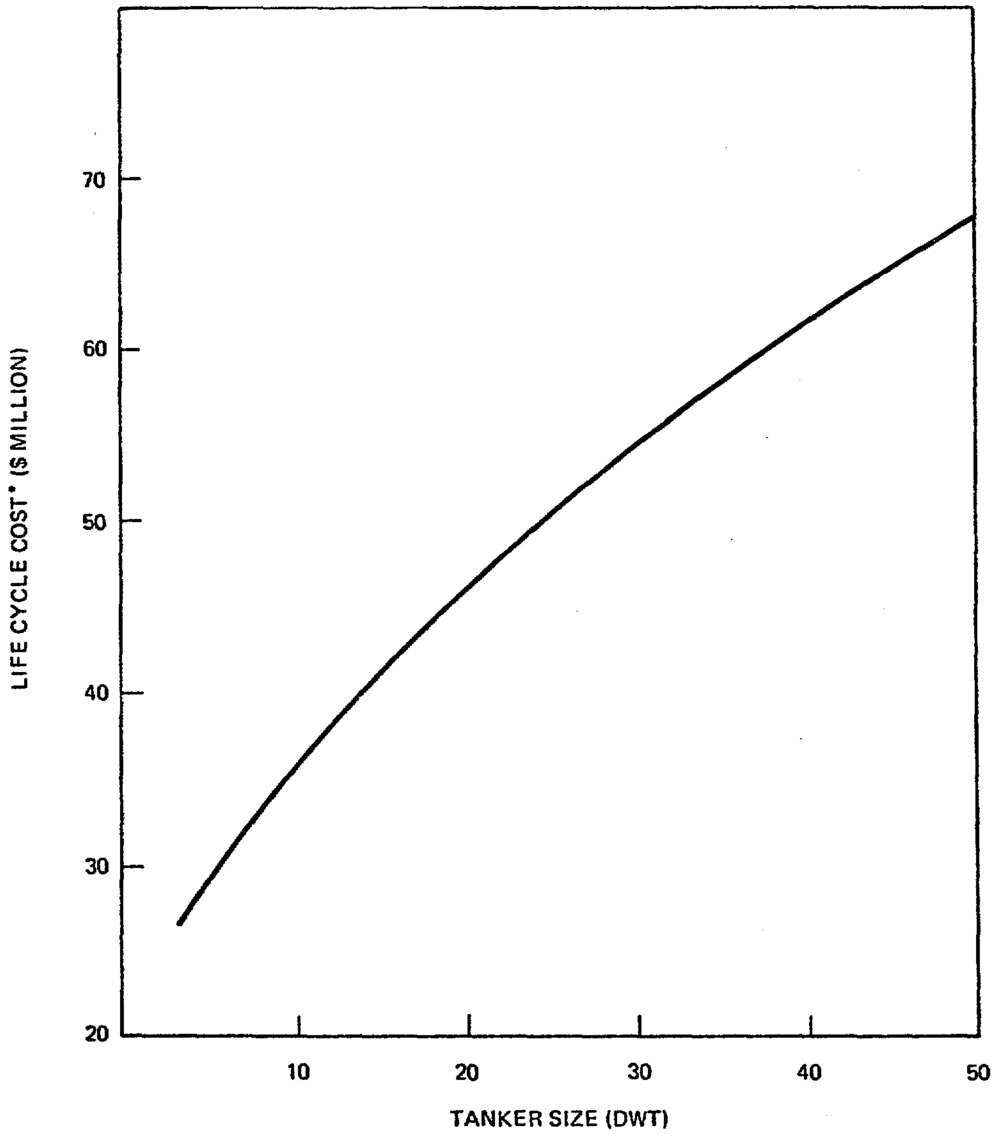
* Based on oil industry historical experience (proprietary source)

FIGURE III-1
Tanker Life-Cycle Cost



*20 YEAR LIFE, NO SALVAGE VALUE

Source: Booz, Allen & Hamilton Inc.

Table III-7
Offshore Pipeline Construction Costs

Diameter (inch)	Cost ($thousand/mile)
6	250
8	262
10	278
12	300
14	325
16	350
18	385
20	420
22	465
24	510
26	576
28	642
30	720
32	810
36	1,010
40	1,290
42	1,440
44	1,660
48	2,210

Source: CEQ 1974, Inflated 31 percent (Ocean Industry pipeline inflation factor) to convert 1972 dollars to 1975 dollars.

4. RESULTS

The results of the economic analysis for hypothetical scenarios outlined in Chapter II are displayed in Figures III-2 through III-5, and individual elements are shown in Table III-8. A discussion of the results for each production site is contained in the following sections.

(1) Economic Analysis Results for Site 1

As shown in Figure III-2, alternate 1-E, utilizing ocean floor storage and direct shipment to the west coast, is the least costly system for reserves lower than two billion barrels. Above this reserve level the pipeline to Port Etches (1-C) is more economical. The shuttle tanker to Valdez (1-B) has the highest cost, becoming more than twice the cost of any other system for large reserve estimates. Consequently, it is unlikely the system would ever be used, simply on the basis of economics. The remaining alternates are considered viable systems, and any one of them may be considered desirable in the event of favorable risk analysis results.

(2) Economic Analysis Results for Site 2

For reserve levels below three hundred million barrels alternate 2-G, with ocean floor storage and direct shipment by long-haul tanker, is the most economical, as indicated in Figure III-3. The pipeline to Kayak Island becomes the optimum system when reserves exceed three hundred million barrels. Both of the alternatives incorporating the shuttle tanker concept are prohibitively expensive. The Valdez and Yakutat pipelines are more costly than the Kayak Island pipeline, and, unless Kayak Island development is prevented by land use regulations, are not economically justifiable.

(3) Economic Analysis Results for Site 3

The results for Site 3, shown in Figure III-4, are similar to those of Site 2, except the change from ocean floor storage and direct shipment to the Kayak Island pipeline occurs when the reserve level exceeds one billion barrels. Other conclusions are the same as for Site 2.

FIGURE III-2
Site 1 Life Cycle Costs

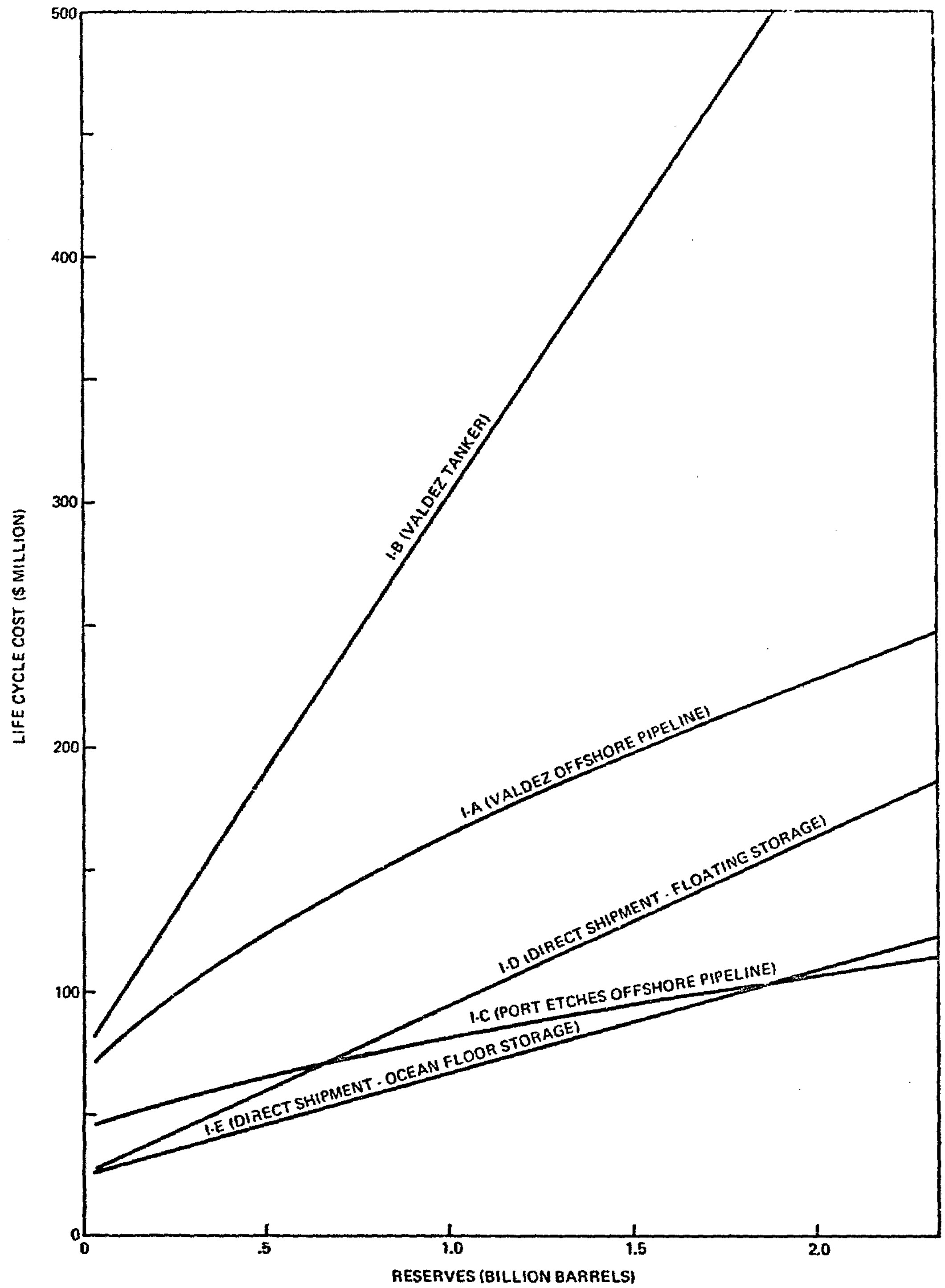


FIGURE III-3
Site 2 Life Cycle Costs

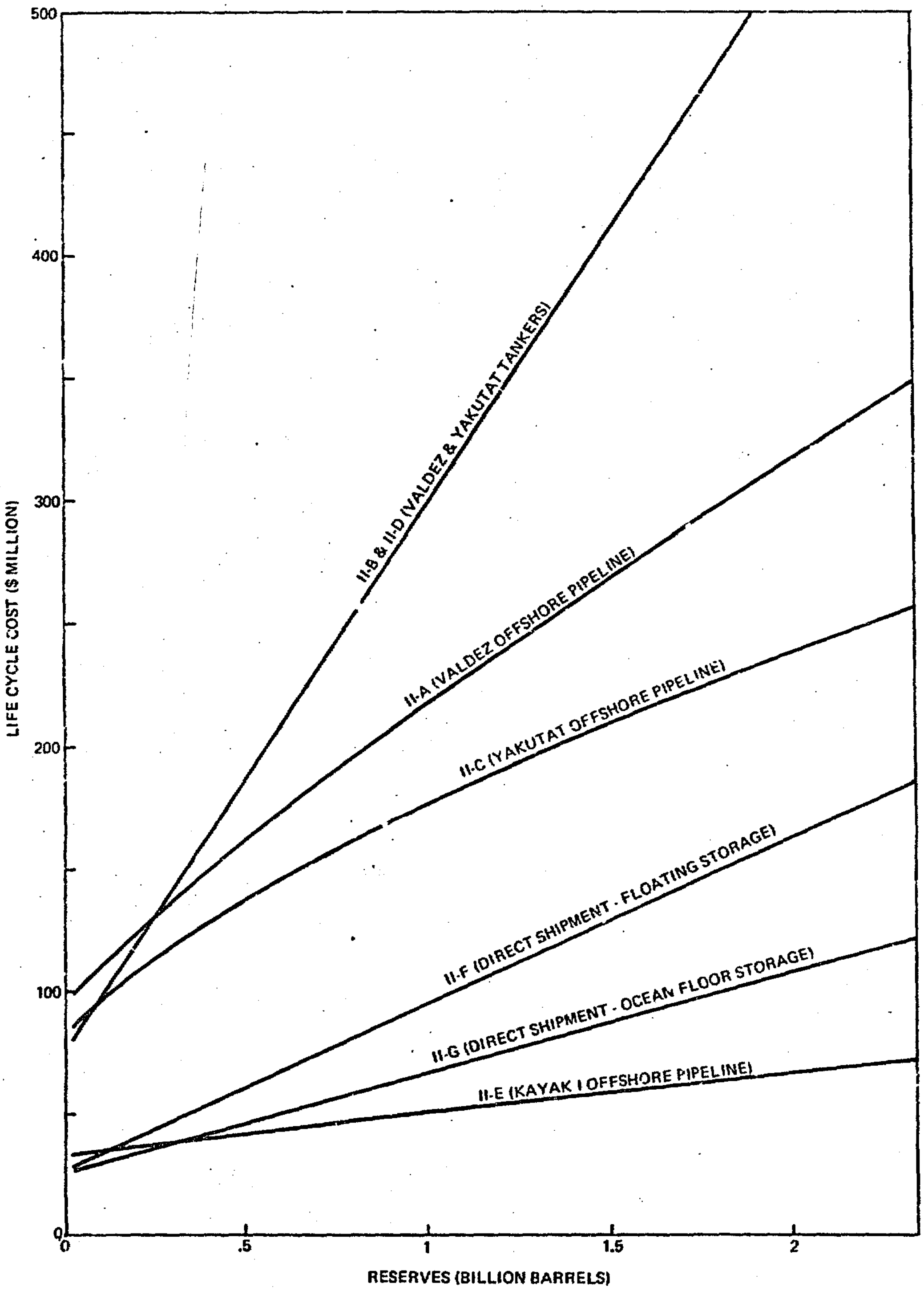


FIGURE III-4
Site 3 Life Cycle Costs

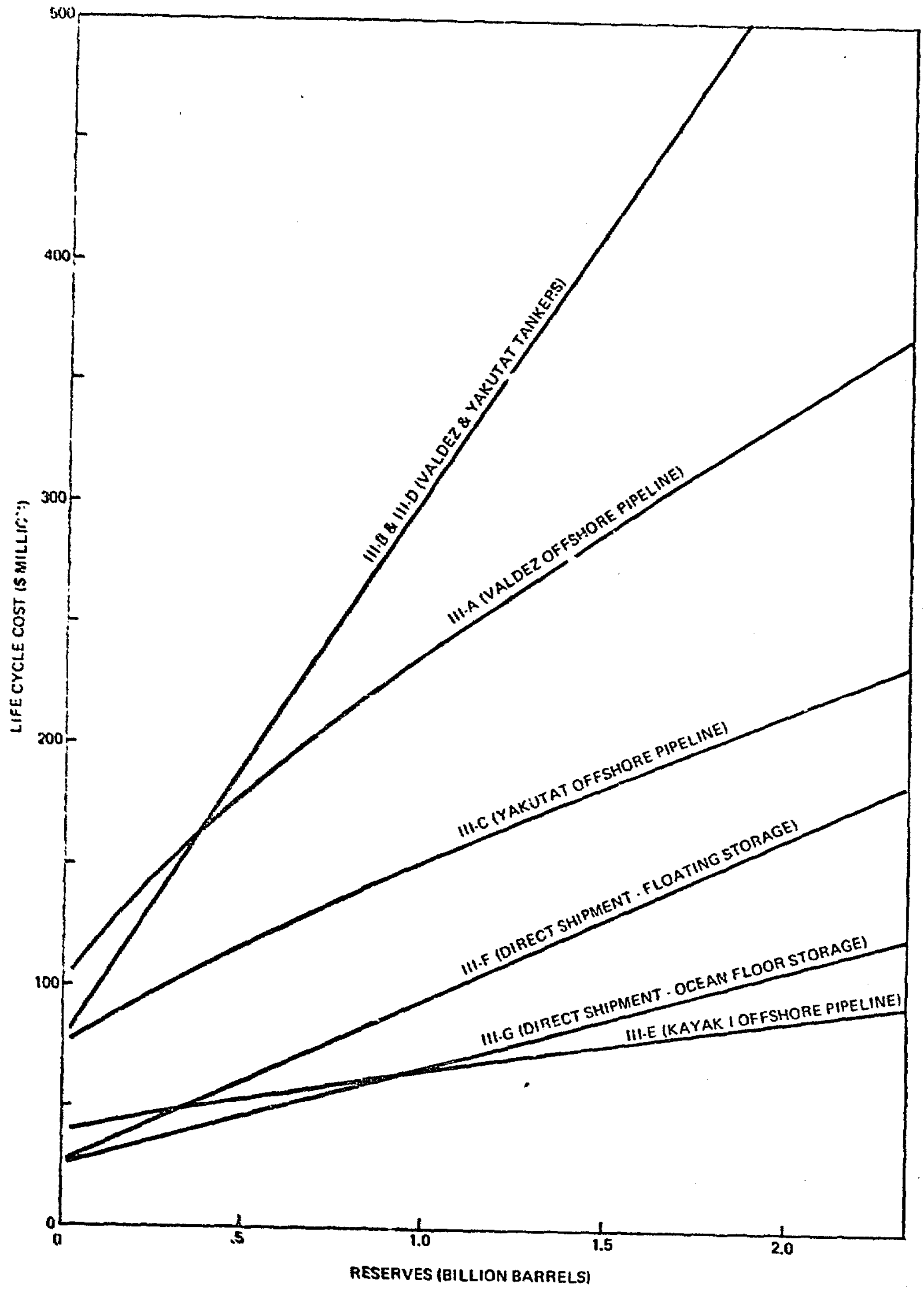
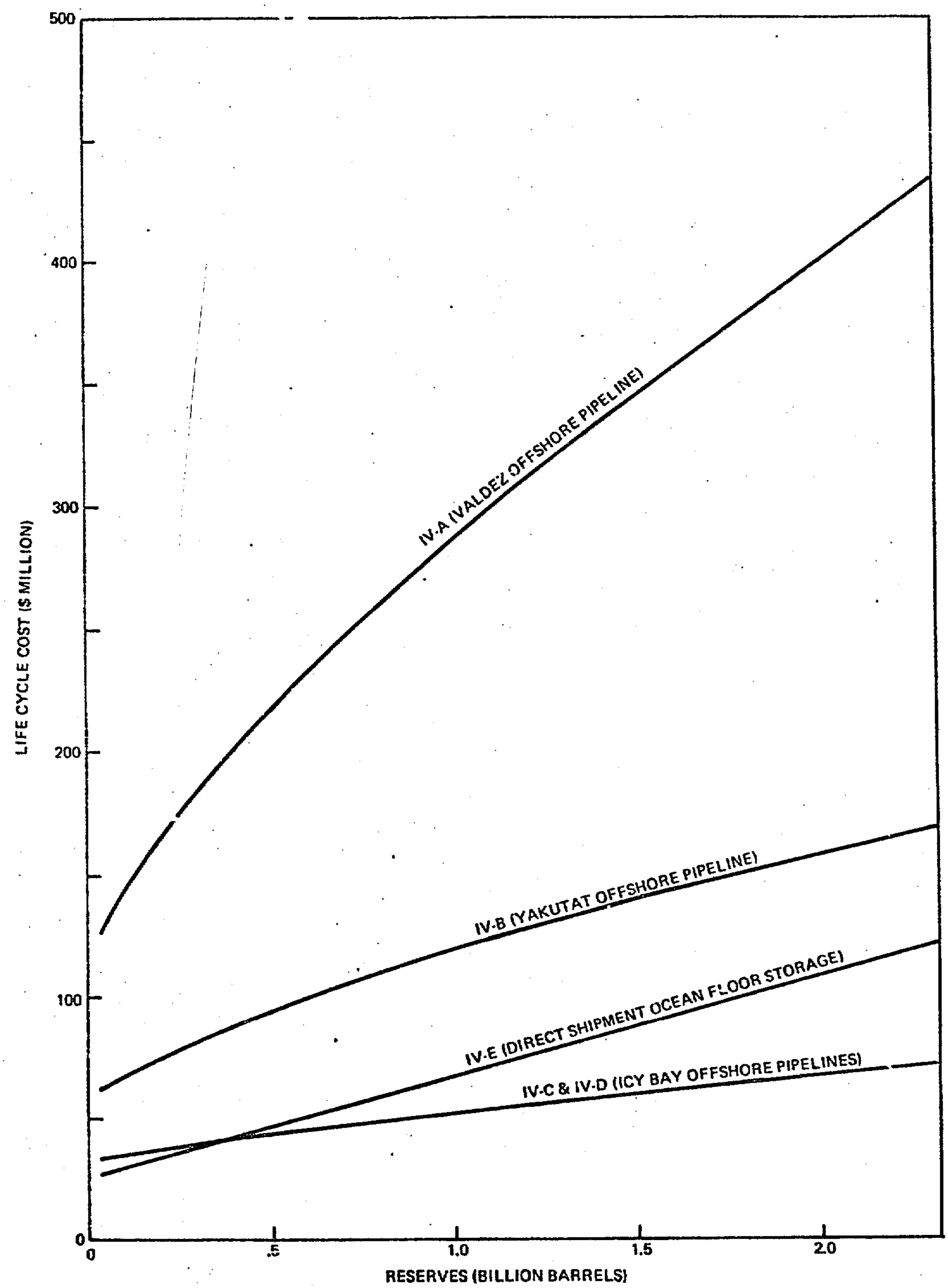


FIGURE III-9
Site 4 Life Cycle Costs



PRODUCTION SITE						INTERMEDIATE TRANSPORTATION			INT
SITE	ALTERNATE	STORAGE		MOORING		MODE		DESTINATION	STORA(
1	A	-	-	-	-	PIPELINE	$104	VALDEZ	ASHORE
	B	FLOATING	$24	SPM	$26	TANKER	$177	VALDEZ	ASHORE
	C	-	-	-	-	PIPELINE	39	PORT ETCHES	ASHORE
	D	FLOATING	69	SPM	26	-	-	-	-
	E	OCEAN FLOOR	41	SPM	26	-	-	-	-
2	A	-	-	-	-	PIPELINE	156	VALDEZ	ASHORE
	B	FLOATING	24	SPM	26	TANKER	177	VALDEZ	ASHORE
	C	–	-	-	-	PIPELINE	135	YAKUTAT	ASHORE
	D	FLOATING	29	SPM	26	TANKER	174	YAKUTAT	ASHORE
	E	-	-	-	-	PIPELINE	10	KAYAK ISLAND	ASHORE
	F	FLOATING	69	SPM	26	-	-	-	-
	G	OCEAN FLOOR	41	SPM	26	-	-	-	-
3	A	-	-	-	-	PIPELINE	172	VALDEZ	ASHORE
	B	FLOATING	24	SPM	26	TANKER	177	VALDEZ	ASHORE
	C	-	-	-	-	PIPELINE	114	YAKUTAT	ASHORE
	D	FLOATING	29	SPM	26	TANKER	174	YAKUTAT	ASHORE
	E	-	-	-	-	PIPELINE	25	KAYAK ISLAND	ASHORE
	F	FLOATING	69	SPM	26	-	-	-	-
	G	OCEAN FLOOR	41	SPM	26	-	-	-	-
4	A	-	-	-	-	PIPELINE	228	VALDEZ	ASHORE
	B	-	-	-	-	PIPELINE	74	YAKUTAT	ASHORE
	C	ASHORE	14	SPM	26	PIPELINE	10	ICY BAY	-
	D	-	-	-	-	PIPELINE	10	ICY BAY	ASHORE
	E	OCEAN FLOOR	41	SPM	26	-	-	-	-

NOTES: 20 YEAR LIFE CYCLE
FINAL TRANSPORTATION COST IS THE MARGINAL COST OF THE EXTRA TIME REQUIRED TO MAKE THE VALDEZ TRIP.

A

Table III-8
Transportation and Storage Systems
Life Cycle Costs
for 1 Billion Barrel Reserve
(Millions of Dollars)

IEDIATE TRANSPORTATION		INTERMEDIATE STORAGE				FINAL TRANSPORTATION			TOTAL
ODE	DESTINATION	STORAGE		MOORING		MODE		DESTINATION	
$104	VALDEZ	ASHORE	$14	DOCK	$26	TANKER	$19	U.S. WEST COAST	$163
$177	VALDEZ	ASHORE	14	DOCK	26	TANKER	19	U.S. WEST COAST	286
39	PORT ETCHES	ASHORE	14	DOCK	26	TANKER	-	U.S. WEST COAST	79
-	-	-	-	-	-	TANKER	-	U.S. WEST COAST	95
-	-	-	-	-	-	TANKER	-	U.S. WEST COAST	67
156	VALDEZ	ASHORE	14	DOCK	26	TANKER	19	U.S. WEST COAST	215
177	VALDEZ	ASHORE	14	DOCK	26	TANKER	19	U.S. WEST COAST	286
135	YAKUTAT	ASHORE	14	DOCK	26	TANKER	-	U.S. WEST COAST	175
174	YAKUTAT	ASHORE	14	DOCK	26	TANKER	-	U.S. WEST COAST	269
10	KAYAK ISLAND	ASHORE	14	SPM	26	TANKER	-	U.S. WEST COAST	50
-	-	-	-	-	-	TANKER	-	U.S. WEST COAST	95
-	-	-	-	-	-	TANKER	-	U.S. WEST COAST	67
172	VALDEZ	ASHORE	14	DOCK	26	TANKER	19	U.S. WEST COAST	231
177	VALDEZ	ASHORE	14	DOCK	26	TANKER	19	U.S. WEST COAST	286
114	YAKUTAT	ASHORE	14	DOCK	26	TANKER	-	U.S. WEST COAST	154
174	YAKUTAT	ASHORE	14	DOCK	26	TANKER	-	U.S. WEST COAST	269
25	KAYAK ISLAND	ASHORE	14	SPM	26	TANKER	-	U.S. WEST COAST	65
-	-	-	-	-	-	TANKER	-	U.S. WEST COAST	95
-	-	-	-	-	-	TANKER	-	U.S. WEST COAST	67
228	VALDEZ	ASHORE	14	DOCK	26	TANKER	19	U.S. WEST COAST	287
74	YAKUTAT	ASHORE	14	DOCK	26	TANKER	-	U.S. WEST COAST	114
10	ICY BAY	-	-	-	-	TANKER	-	U.S. WEST COAST	50
10	ICY BAY	ASHORE	14	DOCK	26	TANKER	-	U.S. WEST COAST	50
-	-	-	-	-	-	TANKER	-	U.S. WEST COAST	67

UIRED TO MAKE THE VALDEZ TRIP.

β

(4) Economic Analysis Results for Site 4

Economic analysis results for Site 4 are depicted in Figure III-5. For reserve levels below three hundred million barrels it is least expensive to use ocean floor storage and direct tanker shipment. Either of the alternates utilizing a pipeline to Icy Bay becomes the most economical system when reserves are above three hundred million barrels.

* * * * *

Three general results of the transportation and storage system economic analysis are stated below:

- Ocean floor storage and direct shipment by tanker are most economical for low reserve estimates
- Pipeline to the nearest suitable shore location is the least expensive alternate when reserve levels are high
- Tanker transshipment is not an economically feasible concept for the Gulf of Alaska.

For intermediate reserve levels, the choice between direct shipment and pipeline depends on the production site location and distance to the nearest port facility.

IV. OIL SPILL RISK ANALYSIS

The oil spill risks associated with tanker transportation, pipeline transportation, and storage facilities are evaluated in this chapter. Risk is measured by the volume of oil that is expected to be introduced to the environment over a 20-year field life, based on recent industry experience. The values are calculated for individual system components, then combined to obtain results for a complete transportation and storage system.

A breakdown of the components for each alternate is shown in Table IV-1. The first component, tanker oil spills, is subdivided into three elements; large spills due to ramming and collision, other large spills, and small spills. Ramming and collision oil spills are treated separately to permit the analysis of specific lease area ship traffic hazards. Other large spills result from groundings, fires, explosions, mechanical breakdowns, tsunamis, and structural failure. Small spills are defined to be less than one thousand barrels, and occur during the loading and unloading operations. The second component is oil spilled from transmission pipelines, which does not include pipe used on platforms or in oil gathering networks. The third component is oil spills associated with the storage of offshore crude oil. The types of storage evaluated are conventional ashore tanks, floating tanks, and ocean floor tanks. The first three sections of this chapter contain the details of the risk analysis for tankers, pipelines, and storage tanks.

A completed table of results, similar to Table IV-1, is contained in the final section of this chapter for the mean reserve level of one billion barrels. A set of graphs illustrates the total volume of oil estimated to be spilled for each alternate for the expected range of oil reserves. The implications of the spill risk analysis are discussed, and general conclusions are stated after reviewing the results from a combined cost and risk perspective.

1. TANKER OIL SPILL RISK

The approach selected for determining the tanker oil spill risks in the Gulf of Alaska combines an analysis of available oil spill statistics in a Bayesian framework with analytically derived worst case oil

Table IV-1
Oil Spill Risk Elements

Site	Alternate	Long-Haul Tanker			Shuttle Tanker			Pipeline		Storage		
		Ramming & Collisions	Other Large Spills	Small Spills	Ramming & Collisions	Other Large Spills	Small Spills	Method 1	Method 2	Ashore	Floating	Ocean Floor
1	A	X	X	X	–	–	–	X	X	X	–	–
	B	X	X	X	X	X	X	–	–	X	X	–
	C	X	X	X	–	–	–	X	X	X	–	–
	D	X	X	X	–	–	–	–	–	–	X	–
	E	X	X	X	–	–	–	–	–	–	–	X
2	A	X	X	X	–	–	–	X	X	X	–	–
	B	X	X	X	X	X	X	–	–	X	X	–
	C	X	X	X	–	–	–	X	X	X	–	–
	D	X	X	X	X	X	X	–	–	X	X	–
	E	X	X	X	–	–	–	X	X	X	–	–
	F	X	X	X	–	–	–	–	–	–	X	–
	G	X	X	X	–	–	–	–	–	–	–	X
3	A	X	X	X	–	–	–	X	X	X	–	–
	B	X	X	X	X	X	X	–	–	X	X	–
	C	X	X	X	–	–	–	X	X	X	–	–
	D	X	X	X	X	X	X	–	–	X	X	–
	E	X	X	X	–	–	–	X	X	X	–	–
	F	X	X	X	–	–	–	–	–	–	X	–
	G	X	X	X	–	–	–	–	–	–	–	X
4	A	X	X	X	–	–	–	X	X	X	–	–
	B	X	X	X	–	–	–	X	X	X	–	–
	C	X	X	X	–	–	–	X	X	X	–	–
	D	X	X	X	–	–	–	X	X	X	–	–
	E	X	X	X	–	–	–	–	–	–	–	X

spill estimates based on transport mode design criteria. Calculations are made for the expected number of spills, the expected spill magnitude, and the expected total volume spilled for three spill types:

- Large oil spills caused by rammings and collisions
- Large oil spills from other accidents
- Small oil spills, less than one thousand barrels.

A thousand barrels is an arbitrary but frequently used dividing line between major and minor oil spills. Rammings and collisions are evaluated separately to permit a more detailed evaluation based on historical data for similar U.S. ports with high density shipping traffic. These accidents should be influenced by the type of port and traffic density, while other causes such as mechanical breakdowns, fires, and structural failures are independent of the port facility. An inspection of navigational charts revealed no unusual grounding hazards for Gulf of Alaska ports, hence, groundings are included with other causes and based on worldwide data. Much of the shore, particularly on the Valdez route, is quite steep and would result in an accident more characteristic of a ramming than a grounding. Oil spills induced by a tsunami are included in the other causes section but are evaluated independently due to their frequent occurrence in the Gulf of Alaska.

(1) <u>Large Oil Spills - Collisions and Rammings</u>

The collision and ramming frequency for ships using the Valdez port was taken to be the average frequency reported* for three U.S. ports with similar approaches. The ports and their respective collision and ramming frequencies are:

- Houston - .000252
- San Francisco - .000193
- Delaware - .000103

Due to unusual wind and fog conditions in the Gulf, Valdez was estimated to have from one to three times the frequency of the above ports. The mean value of this range was used, resulting in a collision and ramming frequency of .000365 per transit for the Valdez port. Other ports in the Gulf

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* U.S. Coast Guard and Corps of Engineers

have substantially shorter approaches, consequently their ramming and collision frequency is estimated to be one fourth of the Valdez figure. When a ramming or collision does occur, approximately ten percent* of the accidents result in a major oil spill. For the one billion barrel reserve case, a 90,000 dwt tanker must make 1,600 trips. When the Valdez port is used, the expected number of ramming and collision spills is calculated as follows:

Number of spills = .000365 x.10 x 1,600

= .0584

The values for different tanker sizes and reserve levels are determined in a similar manner. Ports other than Valdez are expected to have one fourth as many spills.

Ten percent* of, the rammings and collisions leading to a major spill result in a total loss of the vessel, and the entire contents are presumed lost. For the remaining 90 percent of the accidents, a spill is assumed to be six tenths of the vessel's capacity. Combining these values, a weighted average spill volume of 65 percent of the tanker's capacity is obtained.

Returning to the previous example of a 90,000 dwt tanker calling at Valdez and a one billion barrel reserve, the expected volume of crude oil spilled is calculated:

Total Spill Volume = Number of Spills x Spill Magnitude

= .0584 x (.65 x 90,000)

= 3416 tons

= 24,000 barrels

For other ports in the Gulf the expected total spill volume is 6,000 barrels. This analysis applies to both long-haul and shuttle tankers, and results are tabulated in the appropriate columns of Table IV-3.

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* Card, Ponce and Snider, "Tankship Accidents and Resulting Oil Outflows, 1969-1973."

(2) <u>Large Oil Spills - Other Causes</u>

Large oil spills not associated with a ramming or collision are sub-divided into two categories; those caused by incidents adequately represented in the world-wide data base and those caused by a tsunami. The separate evaluation of tsunami related spills is necessitated by their frequency of occurrence in the Gulf of Alaska, which is significantly higher than world-wide experience.

The procedure utilized in this analysis is to calculate the spill frequency, spill magnitude, and total spill volume for the complete world-wide data base,*then remove the spill volume attributable to rammings and collisions on a world-wide basis. This will permit the inclusion of ramming and collision spill volumes for specific ports calculated in the previous section. Lastly, the tsunami spill volume is added.

Following the methodology of Devanney and Stewart,** it is assumed that spill frequency is determined by a Poisson process. This means that the probability of a spill during a particular interval is proportional to the amount of exposure in this interval and spills are generated independently, that is, the probability of a spill is not affected by the last occurrence of a spill. The Poisson distribution has two parameters, the contemplated exposure and the intensity. The intensity of the Poisson process is the mean spill rate. This is an uncertain quantity lying somewhere between 0 and ∞; but prior to examining the spill data, no further judgment can be made. A Gamma distribution with parameters equal to zero suitably characterizes the nature of the intensity variable before observing the data. The parameters of the Gamma distribution are then determined by the data on numbers of spills observed and observed exposure. The exposure variable is taken to be the volume of oil handled.

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* Worldwide tanker spills between 1967 and 1972 reported by ECO, Inc.

** J. W. Devanney III and R. J. Stewart, assisted by Virgil Keith and Joseph Porricelli, "Analysis of Oil Spill Statistics," Report to Council on Environmental Quality, April 1974.

Given a contemplated exposure of t units, the distribution of the number of future spills, n, can be determined. For each n, it is the probability of n spills given each possible value of intensity times that value of intensity summed over all possible intensity values. After some computation, this turns out to be a negative binomial distribution:

$$\rho(n/t, \nu, \tau) = \frac{(n + \nu - 1)!\, t^{n}\, \tau^{\nu}}{n!\,(\nu - 1)!\,(t + \tau)^{n + \nu}}$$

where ν = number of spills observed (99 spills in ECO data)
τ = observed exposure (29.3 x 10^9 barrels in ECO data)
t = contemplated exposure
n = number of spills over field life.

For large samples, the mean of the above distribution, the expected number of spills over the life of the field, is equal to $\bar{n} = \nu\frac{t}{\tau}$. As an example this equation is used to compute the expected number of large spills for the one billion barrel reserve case:

$$\text{Number of Spills} = 99 \times \frac{\text{Reserve}}{29.3 \times 10^9}$$

$$= 99 \times \frac{1 \times 10^9}{29.3 \times 10^9}$$

$$= 3.38$$

To represent spill magnitude, a single-peaked distribution is assumed for simplicity. The Gamma distribution has two parameters which can be varied to obtain an approximation to any single-peaked distribution over the interval 0 to ∞. Since the actual values of the parameters of the Gamma distribution are unknown, they, in turn, are assigned a probability distribution. Devanney and Stewart use a Gamma-hyperpoisson because it is determined by the spill size data sample alone and can be combined with the Gamma distribution without too much analytical complexity. Given the data, the combination distribution of spill magnitude, x, is the product of these Gamma and Gamma-hyperpoisson distributions summed over all possible values of the parameters of the Gamma distribution:

$$f(x/m, s, p) = \int_0^\infty \frac{(xp)^{\rho-1}\, F[(m+1).\rho]\, d\rho}{F(\rho)^{m+1}\, S(m, s, p)\,(x+s)^{(m+1).\rho}}$$

where m = number of spills observed

s $= \sum x_i$ total amount spilled

p $= \prod x_i$ = product of all the individual spill sizes

ρ is a dummy variable

S (m, s, p) is a normalizing constant.

The mean of this distribution approaches the sample mean s/m for large m:

$$\bar{x} = s/m \left[\frac{1}{1 - 1/m}\right] .$$

The equation, $\bar{x} = s/m$, is used to calculate the expected spill magnitude for large spills. An upper bound spill magnitude is established based on worst case spills assumed to be one hundred percent of the tanker's capacity. This was accomplished by eliminating spills in the ECO data base which exceed a tanker's capacity. For the 90,000 dwt tanker the expected spill magnitude is 40,000 barrels.

Total spill volume for a 90,000 dwt tanker and a one billion barrel reserve is calculated as follows:

Total Spill Volume = Number of Spills x Spill Magnitude

= 3.38 x 40,000

= 135,000 barrels

The ramming and collision portion of this spill volume must now be removed. The data reported by Card indicates that 21 percent of the total spill volume is attributable to rammings, leaving 79 percent due to other causes. Spill volume for causes other than ramming and collision are calculated for the previous example:

Spill Volume - Other Causes = .79 x Total Spill Volume

= .79 x 135,000

= 107,000 barrels

Tsunami spills, if any, must be added to this value. These spills occur when a tanker moored at a dock is struck by a tsunami. At any shore terminal in the Gulf of Alaska area, a tsunami is expected .57 times* over the 20 year field life. If a tsunami occurs while a tanker is at a dock, it is assumed that the entire contents of the tanker are spilled. Tanker content is represented by a uniform distribution, with a mean value of 50 percent of the tanker's capacity. Each tanker is docked 24 hours per trip. The expected value of tsunami spills is calculated as follows for the 90,000 dwt tanker and one billion barrel reserve:

$$\text{Tsunami Spill} = (\text{Spill Magnitude})(\text{Tsunami Frequency})(\text{Tanker at Dock Frequency})$$

$$= (.5 \times 90,000)\ (.57)\ \frac{24 \times 1,600 \text{ trips}}{8760 \times 20}$$

$$= 5,600 \text{ tons}$$

$$= 39,000 \text{ barrels}$$

This volume of oil is added to the Spill Volume-Other Causes for alternates that use a dock. A tsunami has no impact on a tanker moored at an SPM in deep water. The results of this analysis are recorded in Table IV-3.

(3) Small Spills

It is expected that all tankers employed in the Gulf of Alaska oil transport will have segregated ballast construction. Under these conditions, significant minor oil spill contributions are expected only from operations at offshore SPM's and onshore terminals. This made it possible to obtain minor spill frequency and magnitude data directly related to loading and unloading operations. Baseline frequencies** are one spill per 50 ship calls at an SPM and one spill per 60 ship calls at a dock.

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* CEQ Report, 1974

** CEQ Report, 1974

These frequencies are adjusted upward to reflect the prevalence of adverse weather and its potential effects on personnel errors.

For minor spills, the CEQ report also provides magnitude data. Losses are given as 4.3×10^{-5} per unit volume handled at an SPM and 1.8×10^{-6} per unit volume handled at a dock. These estimates also should be adjusted, because they reflect some effects that are due to personnel error and therefore, are expected to be aggravated by unfavorable weather conditions.

During three months of the year, spill incidents involving personnel error are pessimistically estimated to be ten times more frequent in the Gulf of Alaska than in worldwide average experience; during the remaining nine months, the frequencies are taken to be equal. By applying this estimate to available breakdowns of frequency and spill volume by pollution incident type,* it has been determined that minor spill frequency estimates should be increased by a factor of 1.374 and expected spill volume per incident decreased by a factor of 0.804 for the Gulf of Alaska. Taken together, these adjustments increase aggregate minor spill volume by a factor of 1.104.

To calculate spill volume due to small spills, the formulas are:

$$\text{Small Spill (SPM)} = 4.75 \times 10^{-5} \text{ (Volume Handled)}$$

$$\text{Small Spill (Dock)} = 1.98 \times 10^{-6} \text{ (Volume Handled)}$$

These spills are incurred each time the oil passes through an SPM or dock.

2. PIPELINE OIL SPILL RISK

Pipeline oil spills are calculated by two methods. The first method uses the historical data base of eight major U.S. oil spills, and assumes that future performance will be the same. The second method recognizes that new technology may reduce the maximum outflow from a leak, and

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* Leotta and Wallace, "The United States Coast Guard's Pollution Incident Reporting System: Its Use in Program Management," Proceedings of 1975 Conference on Prevention and Control of Oil Pollution

eliminates values in the data base that are greater than an engineering estimate of the maximum possible outflow.

The impact of earthquakes and tsunamis on pipeline oil spills is considered insignificant if the following two requirements are satisfied:

- Pipelines must not be routed through areas of poor soil stability
- Pipelines must be buried.

If these requirements are met, there is little chance of pipeline damage. Offshore landslide and slumping, which could destroy large segments of a pipeline, occur in areas with poor soil stability and steep slopes. By avoiding these areas, the risk is averted. When a production site is located in unstable soil an emergency underground shutoff valve is used on the well and the pipeline is immediately routed out of the area.

The design parameters for pipes that must endure the stresses of offshore pipelaying now yield an additional benefit. The pipe is so strong and flexible that it should be unaffected by earthquake vibrations.* While brittle cast iron pipes may rupture during an earthquake, properly routed steel offshore pipelines should continue to function properly.

The current effects of a tsunami are avoided by pipeline burial, and tsunami related soil stability problems can be overcome by suitable pipeline routing.

(1) Method 1

Pipeline spill frequency and magnitude are calculated on the basis of U.S. offshore pipeline spills greater than one thousand barrels between 1964 and 1972 reported by Devanney and Stewart. It is assumed, as in the preceding tanker analysis, that the exposure variable in the Poisson process is volume of oil landed. This assumption implies that the volume of oil

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* CEO Report, 1974, and Transportation Department, American Petroleum Institute

spilled is directly proportional to the volume of oil handled. Spill frequency results of this analysis are shown in Figure IV-1. The mean number of spills over the field life are depicted for a series of reserve estimates. Generally, the mean is approximately 2.5 spills per billion barrels of reserve.

The spill magnitude distribution for the same data base is shown in Figure IV-2. The mean spill size is 1.88 million gallons, or 45 thousand barrels. There is an 80 percent chance, if a spill occurs, that it will be greater than 2,500 barrels of oil, but it is quite unlikely to be greater than 250,000 barrels.

Coast Guard reports are the most complete source of pipeline small spill data, but they do not differentiate clearly among spills that emanated from platforms, gathering lines, or transmission lines. This distinction is crucial in comparing pipelines and tankers since the platform and gathering lines are part of the delivery system in either case. There are indications that a very large proportion of these spills are associated with platforms. Furthermore, the average magnitude of these spills is less than four barrels. The omission of pipeline spills less than one thousand barrels from the analysis due to shortcomings in the data is not serious since they account for a very small percentage of the expected total volume spilled. Onshore liquid pipeline spill data from the Department of Transportation, Office of Pipeline Safety, were also examined but not used because the distinction between very small and very large spills could not be made.

To estimate the total volume of oil spilled due to pipeline transportation, the spill frequency and spill magnitude densities must be combined. The relationship is quite simple to formulate, but difficult to solve. A more straightforward approach is based on the previous assumption that spill magnitude and spill frequency are independent variables. Using this approach, the calculations for large pipeline spills are shown below:

Mean (total spill volume)

$$= \text{Mean (spill magnitude)} \cdot \text{Mean (spill frequency)}$$

$$= 45 \times 10^3 \, \frac{\text{Barrels Spilled}}{\text{Spill Incident}} \cdot 2.5 \times 10^{-9} \, \frac{\text{Spill Incidents}}{\text{Barrel of Reserves}}$$

$$= .00011 \, \frac{\text{Barrels Spilled}}{\text{Barrel of Reserves}}$$

FIGURE IV-1
Frequency of Pipeline Spills
Over Field Life

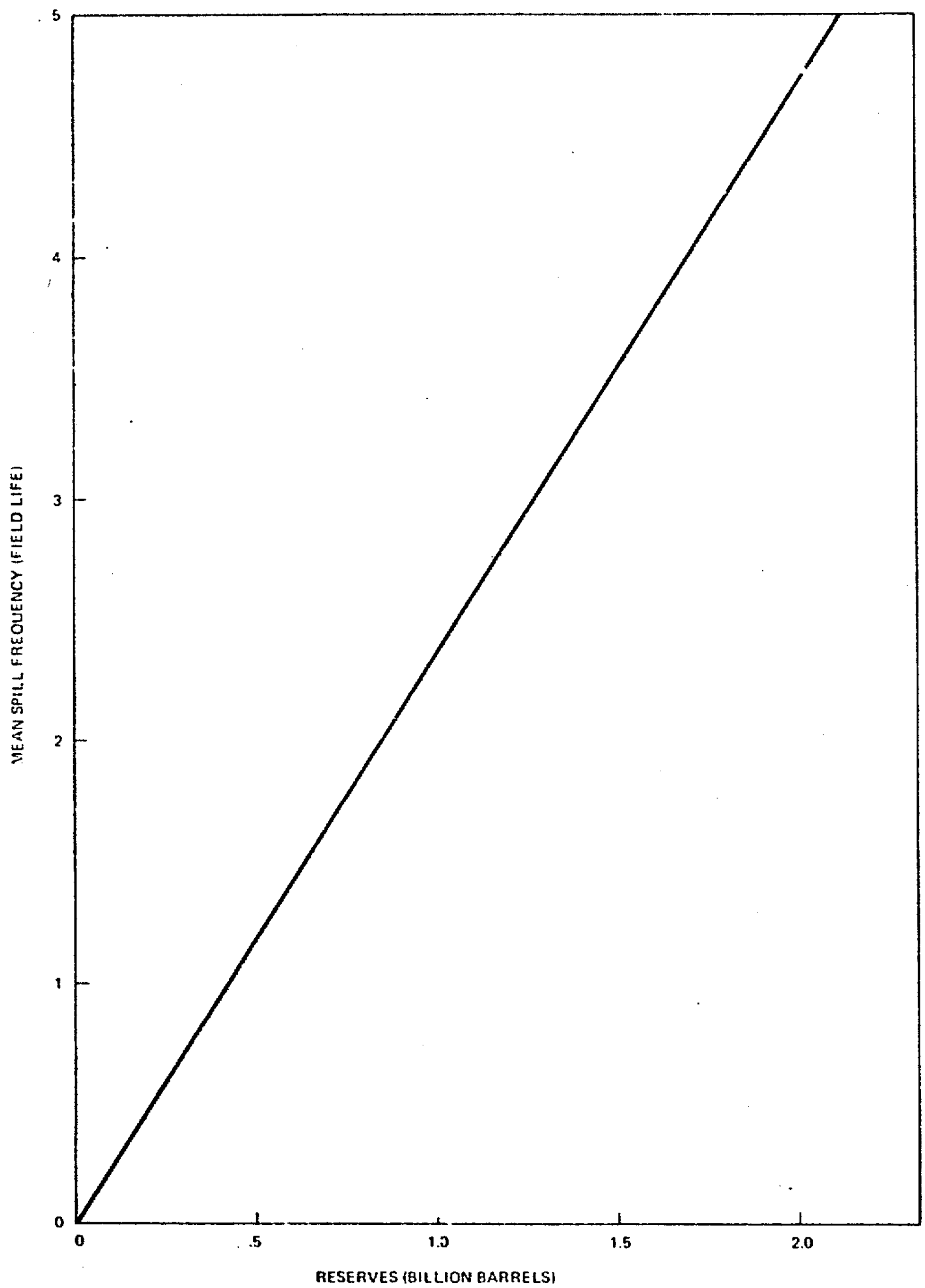
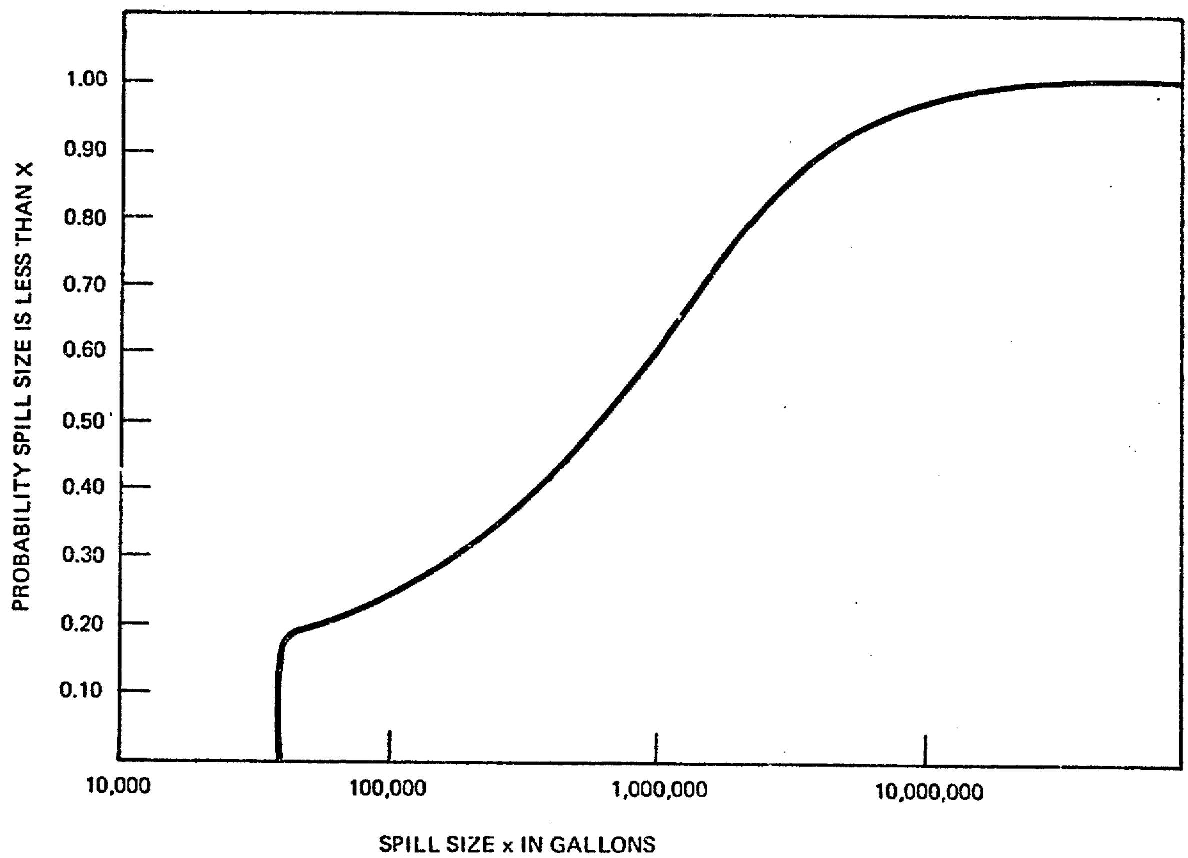


FIGURE IV-2
OCS Pipeline Spill Magnitudes



SOURCE: CEQ 1974

NOTE: BASED ON ALL U.S. OFFSHORE PIPELINE SPILLS OVER 42,000 GALLONS, 1967-1972

This relationship was used to calculate the expected value of pipeline spill volume for Method 1. It should be noted that the variance of spill magnitude is large, and must be given consideration in any evaluation of environmental impact. However, for the purpose of comparing alternate transportation and storage concepts, the average values described previously are a satisfactory representation of total oil spill volume.

(2) Method 2

Method 2 is essentially the same as Method 1 except the maximum spill volume is limited by an engineering analysis of the pipeline. The basis of this analysis is new technology similar to that used on the Trans Alaska Pipeline for the detection of:

- Pressure Deviation
- Flow Deviation
- Line Volume Balance

Pressure deviation is used to detect major line breaks immediately and initiate shutdown procedures. The detection and shutdown process is estimated to require a maximum of six minutes* for completion. Flow deviation is used to identify moderate leaks, on the order of 250 barrels per hour. For detecting small leaks, the line volume balance method is the most accurate. The volume of oil entering and leaving the pipeline is measured automatically, and any imbalance is reported. A balance is performed for each two thousand barrels of flow, and leaks as small as 31 barrels per hour*can be detected.

The catastrophic failure results in the largest oil outflow prior to shutdown, and is used in the estimation of the maximum possible spill. For the one billion barrel reserve estimate, a six minute flow prior to shutdown would spill 1,140 barrels of oil.

Once the shutdown is complete, there can still be a substantial quantity of oil lost by pipeline drainage. The efficient

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* "Project Description of the Trans Alaska Pipeline System," Alyeska Pipeline Service Company

use of check valves will limit the maximum drainage to the longest uphill run of pipeline. The length of these segments was determined for each pipeline and the volume of oil calculated, as shown in Table IV-2. The total spill size was found by adding the flow prior to shutdown and the drainage after shutdown. Each spill in the data base that exceeded the calculated maximum spill was eliminated. The new expected values of spill magnitude are 6,800 barrels for all alternates except IV-C and IV-D, which are 3,800 barrels each. The spill frequency determined in Method 1 is still valid for Method 2.

3. STORAGE OIL SPILL RISK

The analysis of spill risk associated with crude oil storage is separated into three parts, according to the type of storage facility; ashore tanks, floating tanks, and ocean floor tanks. Expected volume of oil spilled for each type of storage is included in the results summarized at the end of this chapter.

(1) Ashore Storage

The spill risks associated with storage of oil ashore in conventional steel tanks are minimal when the following conditions are satisfied:

- The tanks are constructed on bedrock
- The tank elevation is sufficient to avoid tsunami damage
- The tank is surrounded by a retaining dike, capable of holding the entire contents of the tank.

(2) Floating Storage

Floating storage tanks will not be affected by earthquake vibration. The mooring lines will damp out ocean floor vibrations before they reach the tank. In deep water, the passage of a tsunami has no effect. The tsunami height would be considerably less than that of some storm generated waves. Floating tanks in

Table IV-2
Pipeline Drainage for One Billion
Barrel Reserve

Alternate	Longest Uphill Run (miles)	Diameter (inches)	Volume (K barrels)
1-A	15	26	50
1-C	25	22	58
2 A	20	24	55
2-C	25	24	69
2-E	18	18	27
3-A	20	24	55
3-C	25	26	83
3-E	30	20	57
4-A	20	24	55
4-B	25	24	69
4-C	13	18	20
4-D	10	18	15

this study were assumed to use the 100-year storm design criteria, with a safety factor of 2.0. Assuming a Poisson distribution of severe storms, this leads to an expected failure rate of .044 times* for a 20-year field life.

In the floating storage case, a failure is the breakage of moorings. The prevailing winds and currents in the lease area would result in a westward tank drift. A floating storage tank set adrift at Site 1 would probably ground on Wessels Reef, 15 miles to the west. At Sites 2 and 3, the drifting tanks would be carried into the southern tip of Kayak Islands, 20 miles from Site 2 and 40 miles from Site 3. While a nearby vessel may be able to recover the tank prior to impact, the probability of a successful rescue cannot be determined. Hence, the pessimistic assumption of certain grounding was used.

The volume of oil in the tank at any particular time was represented by a uniform distribution. The mean value of this distribution, 50 percent of the tanks capacity, was presumed to be in the tank when the moorings broke. The entire contents would be spilled upon grounding.

When all effects are included, the total oil spilled from floating storage tanks during a 20-year field life is estimated:

$$\text{Oil spilled} = (.044)\,(.5)\,(\text{tank capacity})$$
$$= .022\,(\text{tank capacity})$$

Storage tank capacities for each alternate are given in Tables III-1 through III-6.

(3) Ocean Floor Storage

Ocean floor storage has the highest probability of failure and consequent oil discharge. A tank designed to withstand the 100-year storm with a safety factor of 2.0 is estimated to fail about .044 times during the 20-year field life.* Industry sources indicated than an ocean floor tank could be designed to withstand a 7.2 Richter earthquake with a safety factor of 2.0. Referring to Figure I-3,

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* CEQ Report, 1974

the earthquake failure rate for this tank in the Gulf of Alaska is 2.8 failures in the 20-year field life. While this has a direct impact on spill risk, it would also have economic consequences. The economic aspects were not considered. The effects of tsunami generated currents on ocean floor tanks can be catastrophic, but no quantitative estimate of their damage is available at this time. No reasonable way to approximate the effect was found, so tsunami spill risk was not included in the ocean floor storage analysis.

The volume of oil in the tank was assumed to have a uniform distribution, with a mean value of one-half the tank's capacity. All oil in the tank at the time of failure would be released into the environment. When the failure probabilities are summed, the expected volume of oil lost is calculated as follows:

$$\text{Oil spilled} = (2.8 + .044)\ (.5)\ (\text{tank capacity})$$
$$= 1.422\ (\text{tank capacity})$$

This result indicates that ocean floor storage has more than 60 times the oil spill risk of floating storage, when used in the Gulf of Alaska.

4. SUMMARY

Individual risk elements are shown in Table IV-3 for the one billion barrel reserve level. These tanker, pipeline, and storage spill risks were summed for each candidate transportation and storage system at three reserve levels, and the results are contained in Figures IV-3 through IV-6. An examination of the figures reveals that spill risk is essentially independent of the production site.

The choice between Method 1 and Method 2 for pipeline analysis is subject to debate; new technology may eliminate the very large spills, but only when the equipment is functioning properly. A realistic answer probably lies somewhere between the two sets of results.

The expected volume of oil lost for a two billion barrel reserve when ocean floor storage and direct shipment are used is approximately four million barrels which is 50 times the loss of any other candidate. The remaining candidates are of comparable risk, and no distinction should be made between them on the basis of risk. The variance of spill risk is several times the mean, which would put all candidates, except the one with ocean floor storage, in the same range of oil spill risk.

Table IV-3
Oil Spill Risk Summary for One Billion Barrel Reserve
(thousands of barrels)

Site	Alternate	Long-Haul Tanker			Shuttle Tanker			Pipeline		Storage			Totals	
		Ramming & Collisions	Other Large Spills	Small Spills	Ramming & Collisions	Other Large Spills	Small Spills	Method 1	Method 2	Ashore	Floating	Ocean Floor	With Pipeline Method 1	With Pipeline Method 2
1	A	24	146	2	-	-	-	110	18	0	-	-	282	190
	B	24	146	2	24	127	49	-	-	0	11	-	383	383
	C	6	146	2	-	-	-	110	18	0	-	-	264	172
	D	6	107	47	-	-	-	-	-	-	30	-	190	190
	E	6	107	47	-	-	-	-	-	-	-	1948	2108	2108
2	A	24	146	2	-	-	-	110	18	0	-	-	282	190
	B	24	146	2	24	127	49	-	-	0	11	-	383	383
	C	6	146	2	-	-	-	110	18	0	-	-	264	172
	D	6	146	2	6	127	49	-	-	0	13	-	349	349
	E	6	107	47	-	-	-	110	18	0	-	-	270	178
	F	6	107	47	-	-	-	-	-	-	30	-	190	190
	G	6	107	47	-	-	-	-	-	-	-	1948	2108	2108
3	A	24	146	2	-	-	-	110	18	0	-	-	282	190
	B	24	146	2	24	127	49	-	-	0	11	-	383	383
	C	6	146	2	-	-	-	110	18	0	-	-	263	172
	D	6	146	2	6	127	49	-		0	13	-	349	349
	E	6	107	47	-	-	-	110	18	0	-	-	270	178
	F	6	107	47	-	-	-	-	-	-	30	-	190	190
	G	6	107	47	-	-	-	-	-	-	-	1948	2108	2108
4	A	24	146	2	-	-	-	110	18	0	-	-	282	190
	B	6	146	2	-	-	-	110	18	0	-	-	264	172
	C	6	107	47	-	-	-	110	10	0	-	-	270	170
	D	6	146	2	-	-	-	110	10	0	-	-	264	164
	E	6	107	47	-	-	-	-	-	-	-	1948	2108	2108

FIGURE IV-3
Site 1 Volume of Oil Spilled

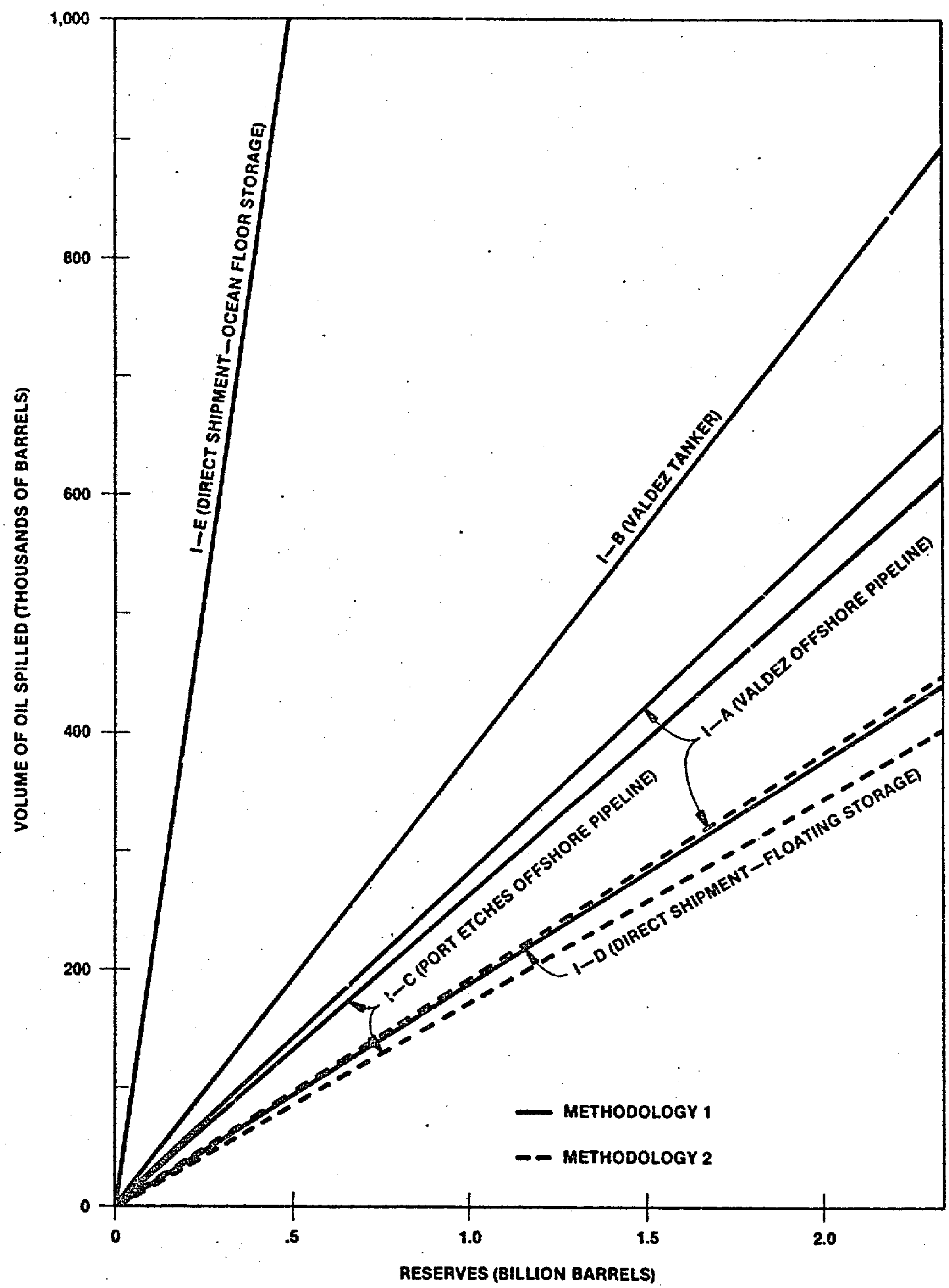


FIGURE IV-4
Site 2 Volume of Oil Spilled

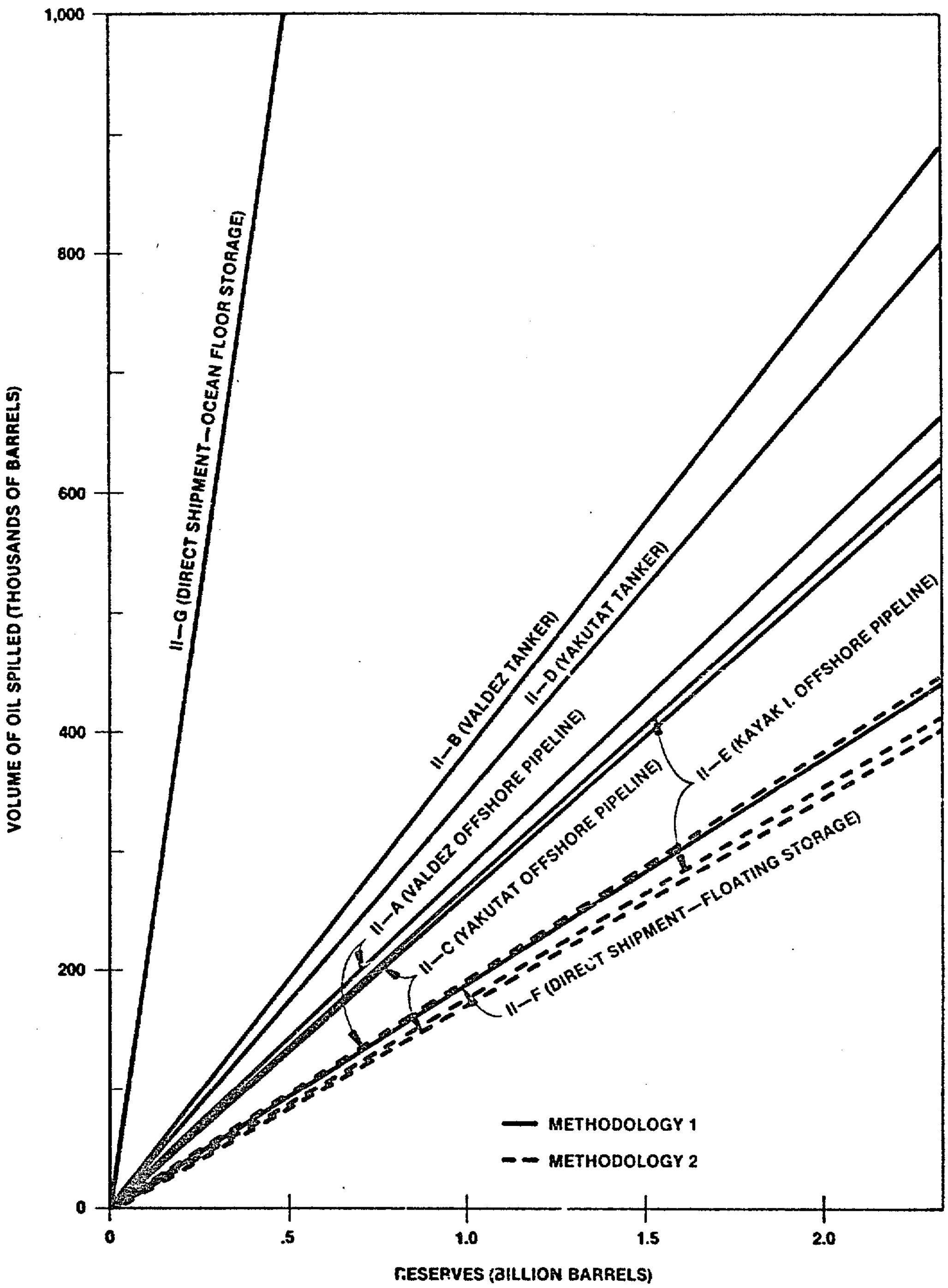


FIGURE IV-5
Site 3 Volume of Oil Spilled

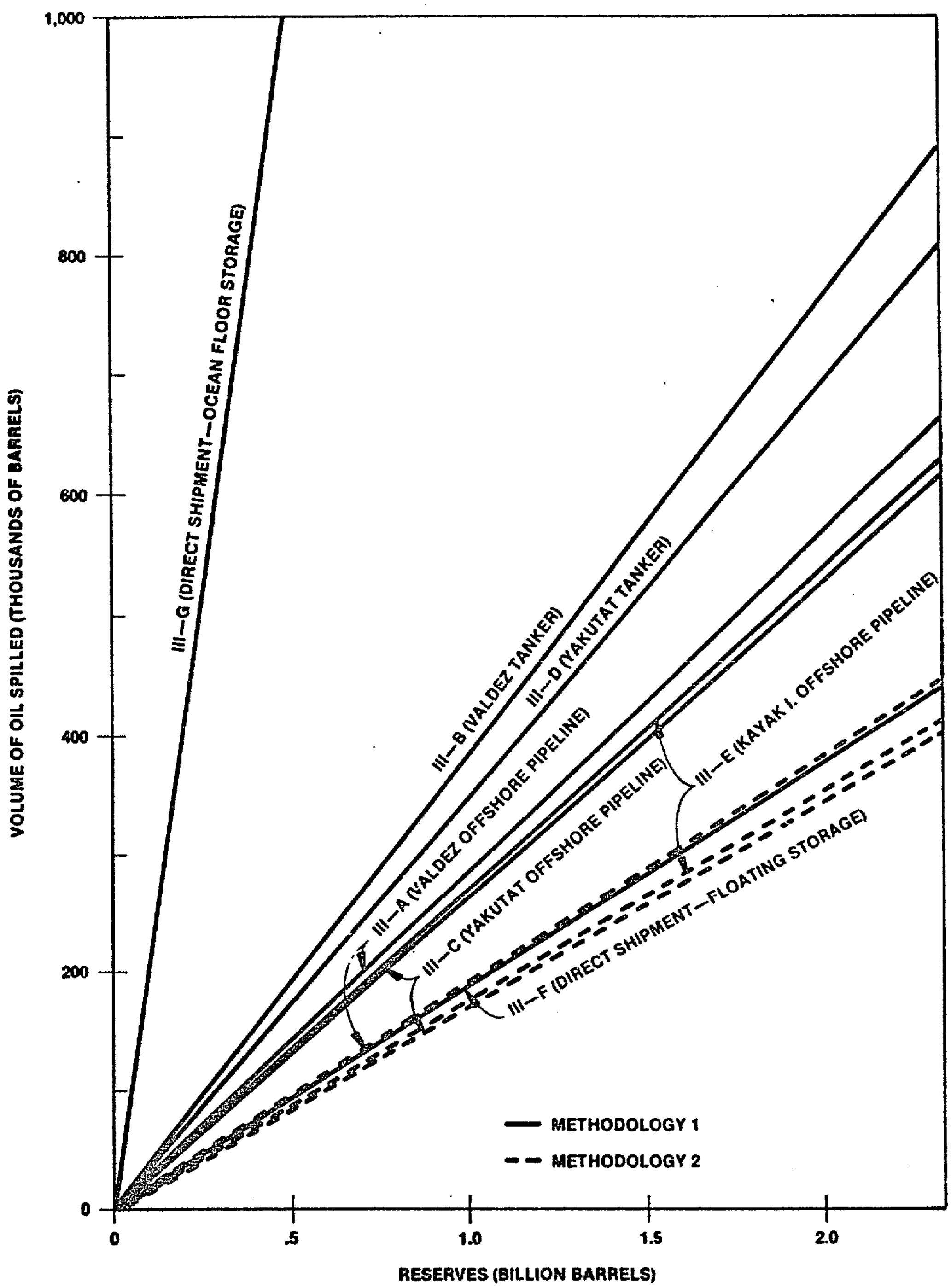
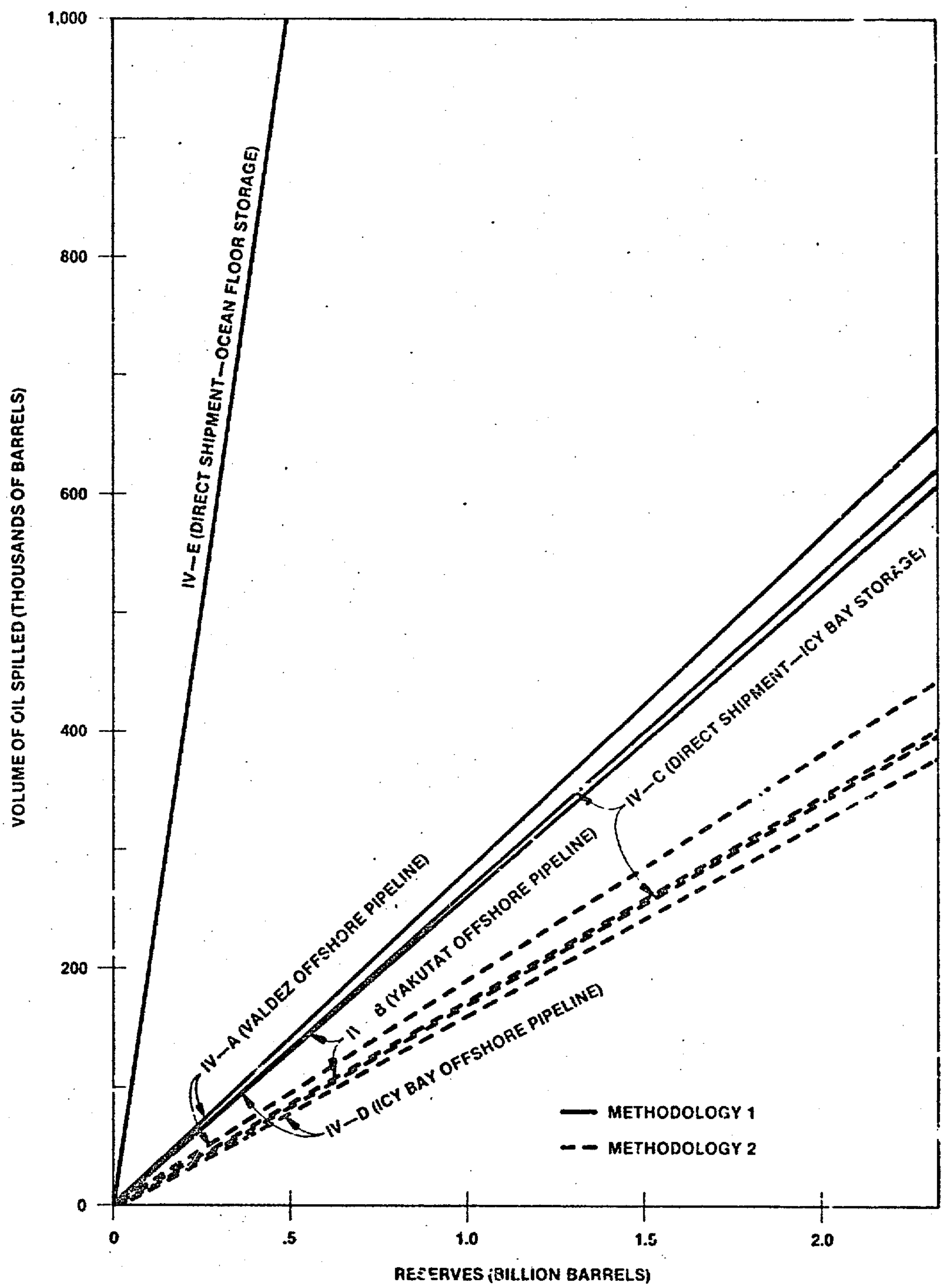


FIGURE IV-6
Site 4 Volume of Oil Spilled



This oil spill risk analysis indicates that ocean floor storage is relatively undesirable for use in the Gulf of Alaska. If significantly higher earthquake design criteria than is incorporated in existing storage systems could be attained, ocean floor storage may become feasible.

A sensitivity analysis was conducted to determine the effect of using larger tankers on the U.S. west coast route. The methodology described earlier indicates a 15 percent increase in tanker oil spill volume if 90,000 dwt tankers are replaced by 180,000 dwt vessels. However, this kind of comparison places tremendous emphasis on a small number of very large spills, and the small increase in spill volume is not considered significant.

The results of this analysis include an assumption of segregated ballast, or a reasonable substitute, to prevent the dumping of oily ballast water. The consequences of relaxing this constraint are now examined. Reference material* indicates that .4 percent of a tanker's cargo may remain in the vessel after offloading. Approximately 15 percent of this clingage is carried out with the ballast water. If no provision is made for ballast water treatment, .06 percent of the oil transported will be spilled with ballast water dumping. The volume of oil spilled for the one billion barrel reserve on the long-haul tanker route is:

$$\text{Spill Volume} = .0006\ (\text{Volume Transported})$$

$$= .0006\ (1 \times 10^9)$$

$$= 600{,}000 \text{ barrels}$$

Alternates that include a shuttle tanker in addition to the long-haul trip would double this volume.

*   *   *   *   *

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* Porricelli, Keith, and Storch, "Tankers and the Ecology," Transactions, Volume 79, 1971.

In view of these results, and the results of the economic analysis, some overall conclusions can be made:

- Tanker transshipment is not an economically feasible concept for the Gulf of Alaska
- Ocean floor storage appears to contain excessive spill risk in the Gulf of Alaska.

The choice between direct shipment with floating storage, and pipeline to the nearest shore facility depends on the production site location and risk methodology used. These results are based on the methodology and assumptions stated in this report, and should not be used out of context.

APPENDIX A

SIMULATION OF TANKER TRANSPORT

Gulf of Alaska climatological conditions could have a severe impact on tanker operations in the lease area. The maximum safe speed of a vessel is directly influenced by the physical environment and traffic density, and the transit time and size of a tanker dictate the storage capacity required. Hence, the effects of weather on tanker operations must be given careful consideration. Three parameters were identified as being critical for tanker operation; wind, fog, and sea state. Each of the three may occur at different levels of intensity, or in a variety of combinations, and the impact is dependent upon the vessels position along the proposed route. Obviously, the hazards associated with wind and fog will hinder tanker movements more in a narrow passage than in relatively open waters.

The magnitude of the problem and the stochastic nature of climatological events make a direct solution impractical, so a Markov process computer simulation model was constructed. The model is used to compute approximate transit time and storage capacity based on tanker size, route description, and a matrix of weather occurrence probabilities. The weather and route input data are discussed in the first section of this appendix. The second section contains a description of the model, and highlights the key elements in its operation.

1. INPUT DATA

For the purposes of this analysis, sea and weather conditions were categorized using four levels of sea state and three levels each of wind speed and visibility:

- Significant wave height
  - Less than 5 feet (1)
  - 5 to 8 feet (2)
  - 8 to 12 feet (3)
  - Over 12 feet (4)

- Wind speed levels
  - 0 to 34 knots (1)
  - 34 to 48 knots (2)
  - Over 48 knots (3)
- Visibility levels
  - Over 5 miles (1)
  - 1 to 5 miles (2)
  - Less than 1 mile (3)

There are 36 possible combinations of these weather conditions. As an example, the first weather condition is defined as (1,1,1) representing the following conditions:

- Wave height less than 5 feet
- Wind speed 0 to 34 knots
- Visibility over 5 miles.

The sequence of numbers continues on through (1,1,2), (1,1,3), (1,2,1), etc., to (4,3,3), which defines these conditions:

- Wave height over 12 feet
- Wind speed over 48 knots
- Visibility less than 1 mile.

Once the categories are defined, the occurrence probability of each must be developed on an hourly basis, to coincide with the time units used in the simulation model. Conceptually, it should be possible to determine such relationships by detailed analysis of synoptic data. However, this may be ruled out by time scales when weather reporting is by days in lieu of hours, and in any event was considered impracticable within schedule constraints.

Available data are not entirely consistent and do not always directly reflect threshholds of navigational interest, for example, two nautical miles versus one nautical mile visibility. For the purpose of this study however, it was possible to obtain suitable inputs for the simulation by a variety of interpolation and approximation techniques.

As has been noted elsewhere,*adequate representations generally can be obtained by lognormal distribution fits to individual weather parameters and by modeling weather persistence as an ergodic Markov process; one in which the probability of a given weather state depends only on the immediately preceding state for a given season and locale.

The transition weather data required for a Markov process was not readily available, and had to be derived from reported information. Several documents**were used to develop state probability tables for wind, visibility, and sea conditions. These tables depict the proportion of each month that experiences each weather size. As an example, the state probabilities for wind are presented in Table A-1. The first line of this table indicates that for the month of January the wind is

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* McCarron, J. K., "The Effects of Weather on Offshore Pipeline Construction in the Gulf of Mexico," 43rd Annual Fall Meeting of Society of Petroleum Engineers of AIME, 1968 (Paper No. SPE 2282).

** Marine Climatic Atlas of the World: Volume II, North Pacific Ocean (NAVAIR 50-1C-529, 1956)

Climatological and Oceanographic Atlas for Mariners: Volume II, North Pacific Ocean (1961)

U.S. Weather Bureau Climatological Data, Alaska, 1967-69

U.S. Coast Pilot 9, Cape Spencer to Beaufort Sea below 34 knots 90.05 percent of the time, between 34 and 48 knots 6.6 percent of the month, and above 48 knots the remaining 3.35 percent.

Table A-1
Wind State Probabilities

Month	Below 34 Knots	34 to 48 Knots	Over 48 Knots
January	.9005	.0660	.0335
February	.9257	.0452	.0291
March	.9522	.0327	.0151
April	.9522	.0327	.0151
May	.9592	.0305	.0103
June	.9898	.0091	.0011
July	.9898	.0091	.0011
August	.9898	.0091	.0011
September	.9522	.0327	.0151
October	.9502	.0345	.0153
November	.9257	.0452	.0291
December	.9005	.0660	.0335

Utilizing the state probabilities and other information contained in the references, a transition matrix was developed. An iterative process was used to generate a feasible set of data for wind and visibility transition probabilities. Since sea state is heavily dependent on the prevailing wind, sea state transitional probabilities are calculated from empirical data and a conditional probability based on the wind.

The transition matrix for wind in the month of January is shown in Table A-2 and is a representative example. If the present wind conditions are 34 to 48 knots, there is a 70 percent chance that the average wind will be below 34 knots during the next hour. There is a 29 percent chance it will remain between 34 and 48 knots, and a one percent chance of exceeding 48 knots. Similar monthly tables were constructed for visibility and sea state, and are utilized by the computer model to probabilistically generate a reasonable sequence of weather events for the Gulf of Alaska.

Table A-2
January Wind Transition Matrix

		Next Hour		
		(1) Below 34 Knots	(2) 34 to 48 Knots	(3) Above 48 Knots
Present Hour	(1) Below 34 Knots	.84	.158	.002
	(2) 34 to 48 Knots	.7	.29	.01
	(3) Above 48 Knots	.08	.12	.80

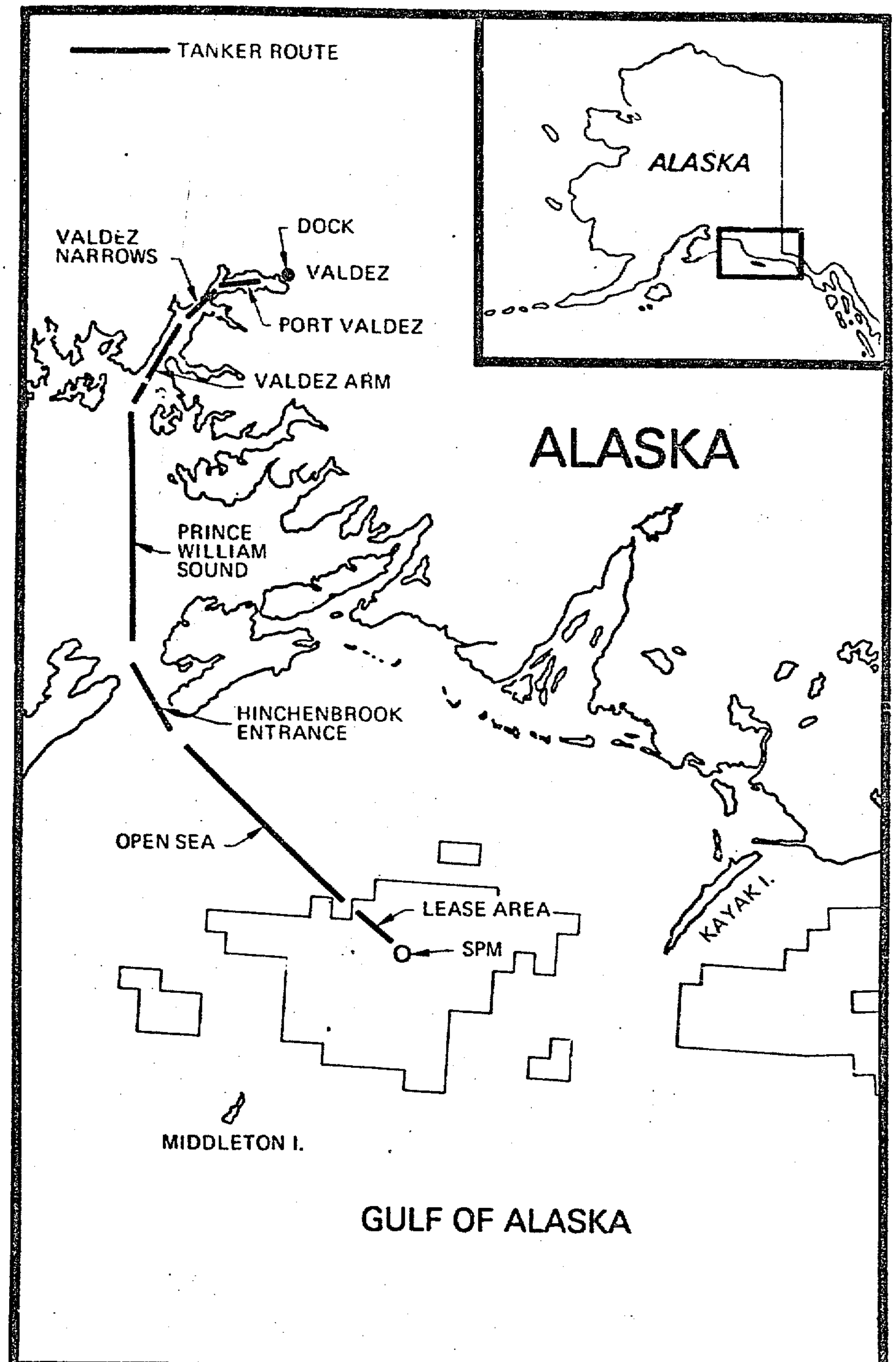
Since the impact of these weather conditions on ship movements will depend on the ship's location, it is necessary to identify the different segments of the voyage. For offshore production sites located in the general vicinity of Middleton Island and a shore terminal located at Valdez, nine specific voyage segments were identified as follows:

- At the single point mooring station
- In lease area
- On open sea between lease area and Cape Hinchinbrook
- In Hinchinbrook entrance
- In Prince William Sound
- In Valdez Arm
- In the Valdez Narrows
- In Port Valdez
- At the Valdez dock.

These segments are illustrated in Figure A-1. The effects of weather on the ship will also vary with the ship status; whether in a loaded or ballast condition. Accordingly, the seven underway segments between the terminals were analyzed for each operating condition. This resulted in 16 location and ship condition elements, which are combined with the 36 weather effects to form a 36 x 16 matrix of

APPENDIX A(6)

FIGURE A-1
Tanker Route Segments



operating states. Each of the 576 operating states is specified by a unique combination of location, ballast condition, wind, visibility, and sea state. An analysis of each operating state was performed by experienced mariners, and one of the following vessel speeds was assigned for each weather condition and location described in the matrix:

- Normal speed
- Half speed
- One-quarter speed
- Stop.

This matrix of operating speeds, together with the transition matrices described previously, constitute the primary input data for the simulation model.

2. DESCRIPTION OF THE MODEL

In the Gulf of Alaska, median duration of a given adverse weather state is on the order of several hours, with persistence and frequency of occurrence varying with the season. The simulation, therefore, employed one-hour time increments and adjusted the weather probabilities on a monthly basis.

This level of detail in terms of both the time increments and changing weather probabilities cause the simulation to be somewhat lengthy. A year's operation was simulated. Because of the complexity and magnitude of the data, one simulation yields a single random sampling that may not represent a typical year of operation. Therefore, ten one-year iterations were made, with some variation from year to year noticeable in the results. The large number of tanker trips within each season increases the effective sample size, and credible empirical relationships are thus obtainable.

Tanker fleets of from one to three vessels were contemplated. At the beginning of each simulated year, the vessels are positioned so that the first has just left the SPM and offshore storage is empty. In a two tanker fleet, the second tanker is at the opposite point on the route, as measured in hours. For three tanker fleets, the second and third are, respectively, one-third and two-thirds of a round trip behind the first. For example, if a round trip requires 48 hours with ideal conditions, the first vessel is at the SPM, and the second and third are 16 and 32 hours away respectively.

At the start of each one-year iteration, the vessels are positioned as indicated above. Initial weather conditions are determined by random draw using the January probabilities for wind and visibility conditions and the conditional probability on sea state. In each successive hour, wind and visibility are determined by random draw and transition probabilities from the current state. Sea state is determined by random draw and conditional transition probabilities. Transition probabilities are redefined monthly to account for seasonal weather variations.

The rate of progress for each vessel is determined by the weather state and the vessel's location and ballast condition. The time remaining in the vessel's current segment of the voyage is reduced by one hour if weather conditions do not require a speed reduction, or by one-half, one-fourth, or zero hours as determined by the 36 x 16 array of vessel speeds. A tanker at the SPM may move away from the SPM if demanded by weather conditions. When this occurs, the tankers' schedule is interrupted for two hours. A vessel approaching the SPM is prevented from reaching the SPM if its predecessor has not finished loading or if weather conditions prohibit loading operations. Subject to these constraints, a vessel advances to the next segment at the end of any hour if it is then within 0.1 hour of the segment boundary.

As each tanker reaches the SPM, the vessel number and time of its arrival are stored in the computer for future use. When the tenth year has been completed, the ten-year minimum, mean, and maximum number of SPM arrivals are displayed for the one-tanker, two-tanker, and three-tanker fleets.

The stored data is then utilized by the computer in the second phase of the program, after the user specifies tanker capacities for each fleet. If the specified capacity is less than the minimum required to transport all production with the given number of tanker arrivals, the program stops and the minimum capacity required to satisfy the demand is displayed. Otherwise, maximum and year-end storage requirements are displayed for each annual iteration together with the largest and mean value of the maxima over the ten iterations.

By increasing tanker capacity until no reductions in storage requirements are observed, the longest interval between successive SPM arrivals can be determined for the ten-year period. The simulation utilizes a fixed production rate of 1,000 tons per hour and a nominal time at the SPM that is predetermined for each computer run. Empirical relationships can be determined from simulations with different times at the SPM. This, together with the longest interarrival times and the ratios between arrivals actually realized and those obtainable under ideal weather conditions, permits scaling of the results to alternate production rates and realistic SPM times for the required tankship capacities.

The tanker size and storage capacities developed by the simulation model are used to calculate life cycle costs for the transportation and storage systems, and are necessary for the determination of oil spill risk.

APPENDIX B

METHODOLOGY FOR ASSESSMENT OF TRANSPORTATION AND STORAGE SYSTEMS COST

1. DETERMINING MAXIMUM BARRELS PER DAY OUTPUT FROM PROPOSED LEASE FIELDS

Referring to Figure B-1, the maximum output in barrels per day is determined by:

$$Q = \frac{\text{Estimated Recoverable Reserves}}{10 \times 365}$$

$$Q = \text{Barrels/Day}$$

Example: USGS estimated recoverable reserves for the Gulf of Alaska is from 100,000,000 to 2,800,000,000 barrels; using the low estimate

$$Q = \frac{100,000,000}{365 \times 10}$$

$$Q = 27,397 \text{ Barrels/Day}$$

2. DETERMINING TANKER CAPACITY, TRANSIT TIME, AND STORAGE CAPACITY

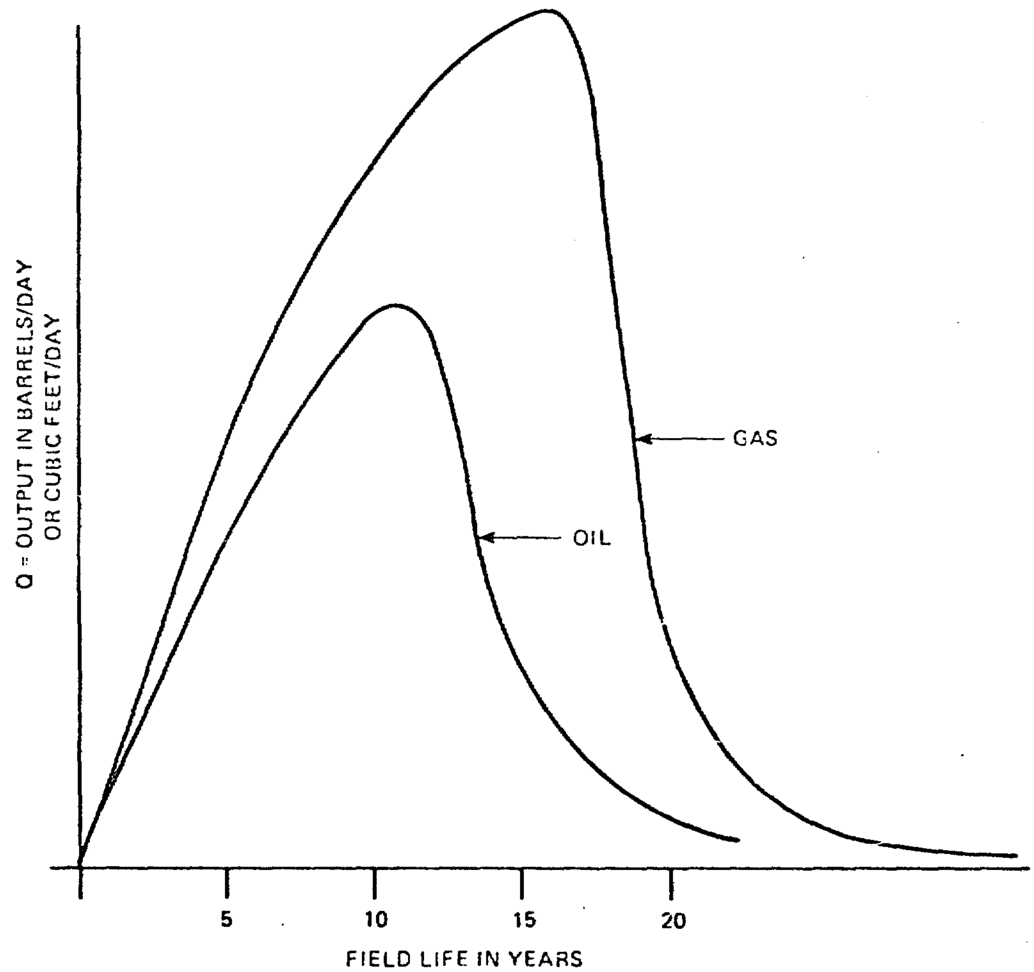
The computer simulation model described in Appendix A calculates approximate storage capacity and transit time, given a tanker capacity. Simulations are made for several tanker sizes with the optimum capacity selected for each system.

3. DETERMINING SHUTTLE TANKER COSTS

For the purposes of this study, it is assumed that newly constructed vessels will be used for short-haul tankers. A survey was made of tankers under construction and their costs were used as tanker capital costs. These costs include the expense of segregated ballast. New construction was used instead of charter as it should more accurately reflect the true cost of a dedicated shuttle tanker system over the next twenty years.

APPENDIX B(2)

FIGURE B-1
Field Utilization Profile



The first operating cost to calculate is fuel costs. The total in-port steaming time will be the time to off-load, plus time to load storage, plus time to load remaining tanker capacity.

Total in-port steaming time = 1.00 day off-load
$\underline{.42}$ days load
1.42

Total at sea steaming time = transit time
= 1.08 days

Given that the fuel consumption rate for a 25,000 ton tanker is

In-port steaming - 80 Barrels/Day
At sea steaming - 500 Barrels/Day

Amount of fuel required for one-trip cycle:

= (80) (1.42) + (500) (1.08)
= 654 Barrels/Cycle

Costs of fuel per cycle at $10.77 per barrel

$$= 654 \times \frac{\$10.77}{\text{Barrel}}$$

= $7,044/Cycle

The annual cost for fuel will equal cost per cycle times the number of cycles per year. The number of cycles per year can be determined by:

$$= \frac{\text{365 Days Per Year}}{\text{Number of Days Per Cycle}}$$

$$= \frac{365}{2.50}$$

= 146 Cycles Per Year

Cost of fuel per year will be the number of cycles per year times the fuel costs per cycle:

$$= \frac{146 \text{ Cycles}}{\text{Year}} \times \frac{\$7,044}{\text{Cycle}}$$

= $1,028,000

Daily operating expenses are:

Wages	$2,550
Subsistence	88
Stores, supplies and equipment	182
Maintenance and repair	730
Insurance	588
Other	70
Total daily expense	$4,208

Annual operating expense = 365 x daily operating expense
= 365 x $4,208
= $1,536,000

The total annual cost for the tanker is the annual operating costs plus fuel costs

Total annual costs = operating costs + fuel costs
= 1,536,000 + 1,028,000
= $2,564,000

4. DETERMINING MARGINAL COST OF LONG-HAUL TANKER SYSTEM

For long-haul service, tankers will be chartered from the existing fleet. Unlike shuttle tankers, the large vessels would be under utilized with low reserves; making as few as eight trips per year. Since every alternate includes long-haul tankers, only the marginal cost of the Valdez trip is needed for comparison.

The marginal costs of tanker systems will consist of chartering and operating expenses. The major operating expense is fuel. Charter costs will vary with the demand and supply of tankers. Based on interviews with current charterers of medium size tankers, a charter rate of eight dollars per dead weight ton per month is used to calculate charter costs.

Fuel costs will vary with the consumption rate for the tanker and marginal transit time.

Total at sea steaming time = marginal transit time

= 0.58 days

Given that the fuel consumption rate for a 90,000 ton tanker is

At sea steaming - 700 Barrels/Day

Amount of fuel required for one-trip cycle:

$$= (700)\ (0.58)$$

$$= 406 \text{ Barrels/Cycle}$$

Costs of fuel per cycle at $10.77 per barrel

$$= 406 \times \frac{\$10.77}{\text{Barrel}}$$

$$= 4373.00\text{/Cycle}$$

Cost of fuel per year will be the number of cycles per year times the fuel costs per cycle. For a one billion barrel reserve the cost is:

$$\text{Annual Fuel Cost} = \frac{80 \text{ Cycles}}{\text{Year}} \times \frac{4373}{\text{Cycle}}$$

$$= 350{,}000$$

The total annual cost for the tanker is the annual charter costs plus fuel costs

$$\text{Total Annual Costs} = \text{Charter Costs} + \text{Fuel Costs}$$

$$= (21{,}500)\ (7)\ (12) + 541{,}000$$

$$= \$2{,}347{,}000$$

5. DETERMINING LIFE-CYCLE COSTS FOR TANKER

Life-cycle tanker costs are based on a 20-year life. The costs are broken down by capital costs and operating costs. Fuel is assumed to escalate at an annual rate of seven percent and other operating costs at a rate of five percent. Future costs are discounted at a rate of ten percent per year. The cost of capital is also assumed to be ten percent. Based on the above assumptions, we can derive the formula below:

$$\text{Life cycle costs} = I + \sum_{N=1}^{20} F\ (.97)^{N-1} + \sum_{N=1}^{20} O\ (.95)^{N-1}$$

I = Initial investment
F = Fuel costs/year
O = Operating costs/year
N = 20-year field life

Example: To determine life-cycle costs for a new 25,000 dwt tanker.

Capital costs	= \$16,000,000
Annual operating costs	= \$ 1,536,000
Annual fuel costs	= \$ 1,028,000
Discount rate	= 10 percent
Interest rate	= 10 percent
Inflation rate (fuel)	= 7 percent
Inflation rate (operating)	= 5 percent
Life-cycle	= 20 years

$$\text{Life cycle costs} = I + \sum_{N=1}^{20} F\,(.97)^{N-1} + \sum_{N=1}^{20} O\,(.95)^{N-1}$$

$$= 16{,}000{,}000 + \sum_{N=1}^{20} (1{,}028{,}000)\,(.97)^{N-1}$$

$$+ \sum_{N=1}^{20} 1{,}536{,}000\,(.95)^{N-1}$$

$$= 50{,}436{,}000$$

For a chartered tanker there is no capital cost and the charter expense is treated as an operating cost.

6. MOORING SYSTEM COST

The capital cost for a heavy weather SPM is approximately \$20 million,*with annual operating costs of \$500,000.* The construction cost of a shore port facility in the Gulf of Alaska ranges from \$15 to

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* Proprietary source in oil industry

$25 million* depending on location and production capacity. The average figure of $20 million was used in the study.

To determine the life-cycle cost of a mooring facility:

Capital costs	= $20,000,000
Annual operating costs	= $ 500,000
Discount rate	= 10 percent
Interest rate	= 10 percent
Inflation rate	= 5 percent
Life-cycle	= 20 years

$$\text{Life-cycle costs} = I + \sum_{N=1}^{20} O\ (.95)^{N-1}$$

$$= \$20{,}000{,}000 + \sum_{N=1}^{20} \$500{,}000\ (.95)^{N-1}$$

$$= \$26{,}231{,}000$$

7. DETERMINING PIPELINE SIZE (DIAMETER)

The diameter of a pipeline is a function of desired throughput, distance or length of the pipeline, and pressure, or more specifically, pressure drop per mile of pipeline. The formula below approximates the relationship between pipe diameter and the above factors.

$$P = \frac{Q^{1.748}\ V^{.252}\ S}{156.4D^{4.748}}$$

P = Pressure loss, psi/mile

Q = Throughput, barrels/day

V = Kinematic viscosity

S = Specific gravity

D = Inside diameter of pipe

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* Proprietary source in oil industry

A graphic display of this formula is shown in Figures B-2 and B-3. The graphs are displayed in terms of barrels per hour, pressure loss per mile and pipe size in inches (I.D.). Therefore, with a few basic assumptions, pipe diameter can be determined.

Example: Site 1 pipeline to Valdez, low estimate of recoverable reserves.

Assumptions:

- There is full flow through the pipe
- There is no pressure loss due to configurations (elbows, curves, etc.) in the pipeline
- The pipeline discharge pressure from the gas oil separator is 1,000 psi
- The pipeline pressure at the receiving point is 20 psi
- The pipeline is designed for anticipated maximum throughput at the peak of the field life.

From Section 1

$$Q = 27{,}397 \text{ bbls/d}$$

$$Q = \frac{27{,}397}{24}$$

$$= 1{,}142 \text{ barrels/hour}$$

Since the pipeline is 121.0 miles long

Length pipeline = 121.0 miles

$$P = \frac{1{,}000\text{-}20 \text{ psi}}{121.0 \text{ miles}}$$

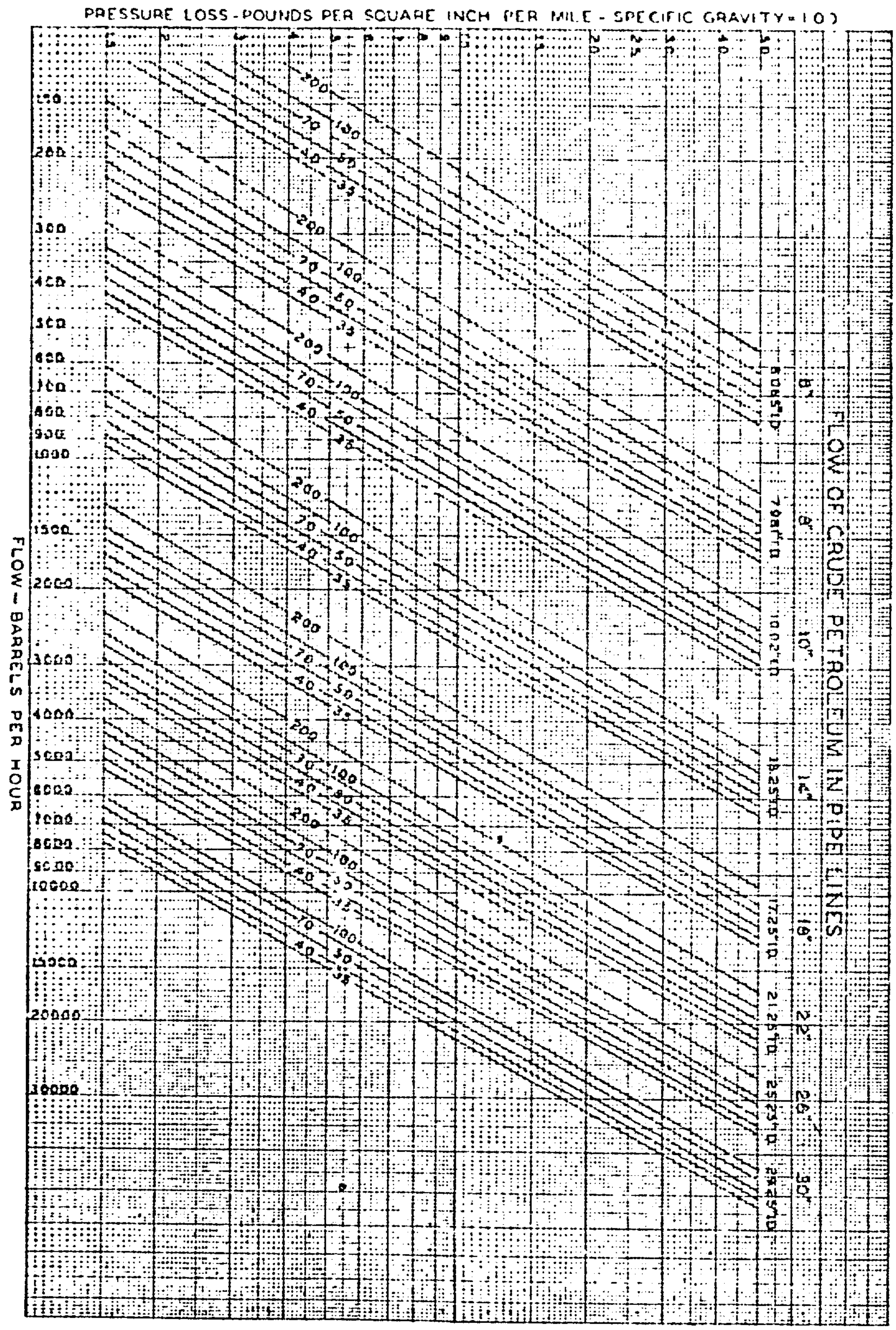
$$= 8.1 \text{ psi/mile}$$

From Figure B-3

D= 12 inches I.D.

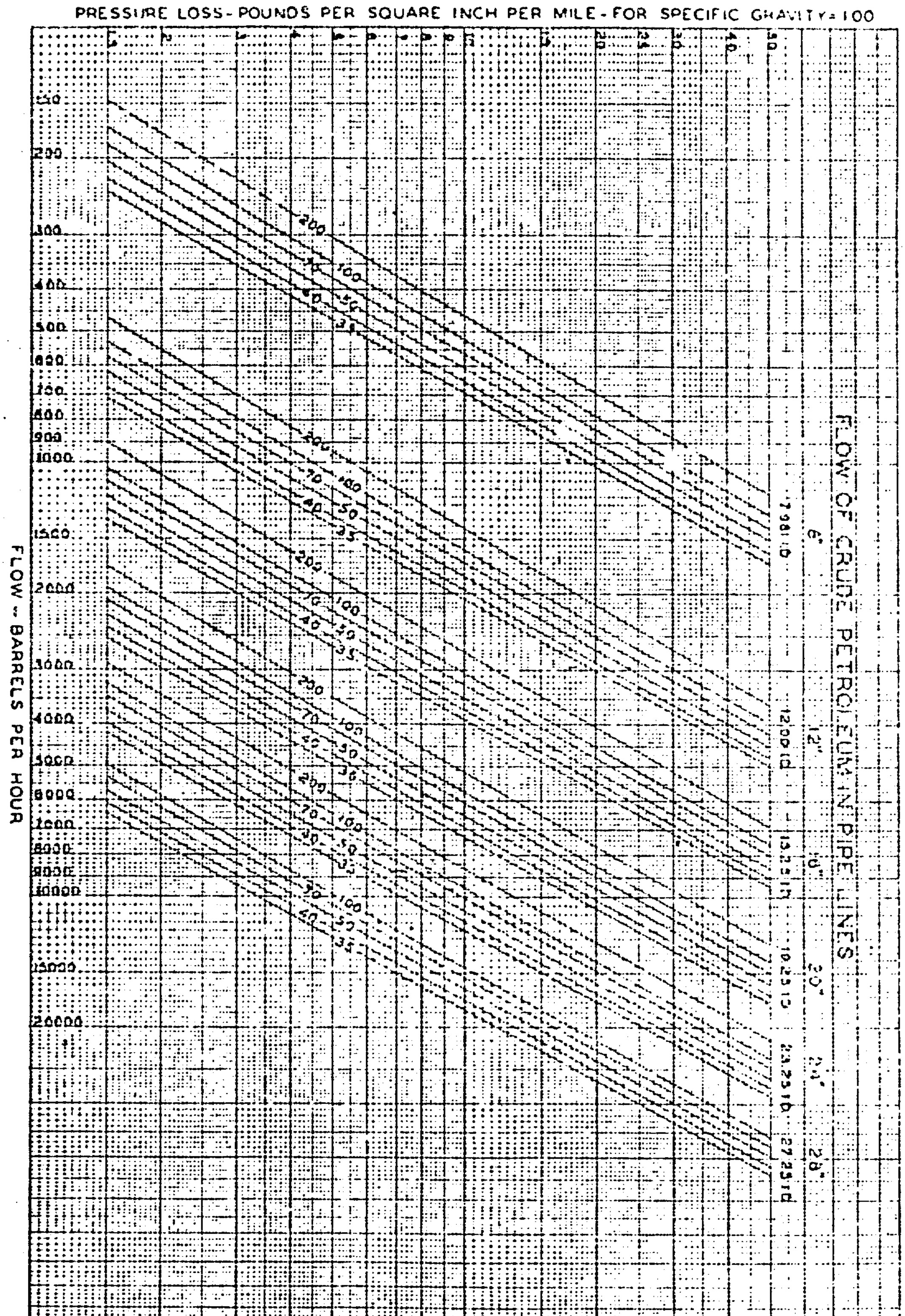
APPENDIX B(9)

FIGURE B-2
Flow Chart for Crude Oil in Pipelines



APPENDIX B(10)

FIGURE B-3
Flow Chart for Crude Oil in Pipelines



8. DETERMINING PIPELINE CAPITAL COSTS

As mentioned previously, pipeline costs are a function of numerous factors. Depth and size, however, are the major inputs for costing off-shore pipelines. Since pipelaying in depths which exist in the Gulf of Alaska is within the capability of present technology, cost data was drawn from published literature.

Table B-1 lists the costs of offshore pipe construction for various size pipe. The original figures were in 1972 dollars, and were inflated 31 percent*to arrive at the 1975 values shown in the table. These costs are lower than those used in the Southern California study**due to much shallower water in the Gulf of Alaska. Present technology is sufficient for the Gulf, while Southern California will require new developments in deep water pipelaying.

Table B-1
Offshore Pipeline Construction Costs

Diameter (inch)	Cost ($Thousand/Mile)
6	250
8	262
10	278
12	300
14	325
16	350
18	385
20	420
22	465
24	510
26	576
28	642
30	720
32	810
36	1,010
40	1,290

Source: CEQ 1974

* Ocean Industry

** "A Risk and Cost Analysis of Transporting Southern California Outer Continental Shelf Oil," July, 1975.

Example: Site 1 to Valdez

Costs for a 12-inch I.D. pipeline over a distance of 121.0 miles

From Table B-1

Cost/mile = $ 300,000
Cost = 300,000 (121.0)
= $36,300,000

9. DETERMINING PIPELINE OPERATING COSTS

Pipeline operating costs have been estimated at four percent* of construction costs. This would include costs to operate, monitor, maintain, and repair the pipeline over the life of the field.

Example: Site 1 to Valdez

Operating costs = .04 (construction costs)
= (.04) (36,300,000)
= $1,452,000/year

10. DETERMINING PIPELINE LIFE-CYCLE COSTS

Pipeline life-cycle costs are determined by the same formula as that of tankers.

Example: Site 1 to Valdez pipeline, life-cycle costs are computed based on the following assumptions:

Capital costs	= $36,300,000
Annual operating costs	= $ 1,452,000
Discount rate	= 10 percent
Interest rate	= 10 percent
Inflation rate	= 5 percent
Life-cycle	= 20 years

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* Based on oil industry historical experience (proprietary source)

$$\text{Life cycle costs} = I + \sum_{N=1}^{20} O\,(.95)^{N-1}$$

$$= 36{,}300{,}000 + \sum_{N=1}^{20} (1{,}452{,}000)\,(.95)^{N-1}$$

$$= \$54{,}395{,}000$$

11. DETERMINING STORAGE COSTS

The cost of onshore storage was based on a survey of recent construction. In the lower 48 states, steel tanks cost approximately five dollars per barrel of storage capacity, including site preparation. It was estimated the same tanks would cost 100 percent more to construct in Alaska, due to the remote location. The cost used in the analysis was ten dollars per barrel of capacity.

Floating and ocean floor storage costs were approximated by taking the cost of new production and storage platforms described in Chapter II, and subtracting the cost of a platform without storage. The marginal cost of storage was calculated on a per barrel basis, and was found to be fifty dollars per barrel for floating storage and thirty dollars per barrel for ocean floor storage. This represents the cost of adding storage to a platform, and is a reasonable approach since a production platform must be provided in any case.